



Marine and Tropical Sciences Research Facility

The influence of zoning (closure to fishing) on fish communities of the deep shoals and reef bases of the southern Great Barrier Reef Marine Park

Part 1 - Baited video surveys of the Pompey, Swain and Capricorn-Bunker groups of reefs off Mackay and Gladstone



M. Cappo, A. MacNeil, M. Stowar and P. Doherty



Australian Government
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Acronyms and Abbreviations

AIMS		Australian Institute of Marine Science
BRUVS	.....	Baited Remote Underwater Video Stations
FOV	.....	BRUVS field of view
FRV	.....	Fisheries research vessel
GBRMP	.....	Great Barrier Reef Marine Park
GBRWA	.....	Great Barrier Reef World Heritage Area
GLM	.....	Generalised linear models
GLME	.....	Generalised linear mixed-effect (models)
GPS	.....	Global Positioning System
MPA	.....	Marine Protected Area
MTSRF	.....	Marine and Tropical Sciences Research Facility
pers. comm.	.....	personal communication
PVC	.....	Polyvinyl chloride
RAP		Representative Areas Program (2004)
SCUBA		Self-Contained Underwater Breathing Apparatus

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Executive Summary

This report presents the results of a single survey (Summer 2009) of sixteen pairs of large, discrete, deepwater reef bases in the southern Great Barrier Reef. Within each pair, one reef was zoned 'green' (closed to fishing) and the other 'blue' (open to all fishing).

The demersal habitats and vertebrate communities were sampled using non-extractive baited remote underwater video stations (BRUVS), which revealed a diverse (~360 species) fauna of fish, sharks, rays and sea snakes. This fauna included species prized by fishers, taken as bycatch, or not vulnerable to hook and line fishing.

Generalised linear models (GLM) and generalised mixed-effects models were used to estimate the influence of zoning on the maximum number of fish observed by each BRUVS (*MaxN*) for specific components of the fish community, showing that zoning had a significant effect on the observed *MaxN*, but this was detectable mainly in habitats dominated by corals. *MaxN* for aggregated groups of species taken as bycatch were similar in both 'blue' and 'green' zones, but the 'target' group *MaxN* was higher around green reefs in coral dominated habitats. In this habitat type, 'target' species were about 1.5 times, and unfished species about 1.9 times, as abundant in the 'green' zones as the same groups in the 'blue' zones.

Individual species showed distinct responses, with grey reef sharks (taken as bycatch) having higher *MaxN* in a range of habitat types on green reefs, and the Venus tuskfish having lower *MaxN* on green reefs. The prized deep-water coral trout, red emperor and red-throat emperor had higher *MaxN* values around the green reefs in coral dominated habitats, but not by large margins. For every ten BRUVS sets, there were about eleven coral trout, six red emperor and five grey reef sharks more in green zones than in similar coral dominated habitats of blue zones.

We lacked any data on spatial and temporal variation in fishing effort in the deep habitats around reef bases, and for this reason our results should not be extrapolated regionally or throughout the Great Barrier Reef Marine Park (GBRMP). It is plausible that fishing around the deep reef bases in these remote southern reefs occurs (if at all) at such a low level that the Representative Areas Program (RAP) 2004 zoning has had little effect on local fish abundance in areas already under little to no fishing pressure.

It is also possible that the deep, complex habitats around the reef bases extended continuously between reefs within some pairs, allowing fish unrestricted passage across zone boundaries. Our sampling was the first exploration of these habitats, and we could not stratify sampling by habitat type or extent. These results are in contrast to previous surveys of the discrete tops and slopes of the same reefs that have detected major impacts of the zoning plan on shallow-water coral trout, which comprise the major target of the long-range commercial fishery for the 'live reef fish' trade.

Introduction

The major revision of the GBRMP zoning plan in 2004 greatly increased the proportion of no-take 'green' zones (where extractive activities such as fishing are completely prohibited) to over thirty percent of the total area of the marine park (Fernandes *et al.* 2005). The increase in green zones in the rezoning was anticipated to have measurable benefits to the maintenance and improvement of conservation goals and sustenance of viable fisheries in the Great Barrier Reef World Heritage Area (GBRWHA). This established an imperative to assess and monitor fish populations and habitats in areas with, and without, a previous history of data collection.

The survey of fauna and flora inhabiting shallow, emergent reefs is well established through the use of SCUBA, and there has been a recent proliferation in reports of the rapid and positive changes in populations of fished species, such as coral trout (Begg *et al.* 2005) and changes in community structure of fishes (Graham *et al.* 2003; Williamson *et al.* 2004).

Prevailing theory predicts a 'top down' control of fish communities in Marine Protected Areas (MPAs) where the density of prey species is inversely proportional to the increases in numbers of 'target' predators. However, Ayling and Choat (2008) have found that *all* trophic groups are present in higher densities in the 'pink' zones of greatest protection on the central GBRMP, suggesting a 'facilitation' effect amongst and within species (pers. comm., J. H. Choat, James Cook University). This is a novel explanation emerging as knowledge increases about the skills and selectivity shown by post-larval reef fish at settlement.

The most compelling study of effects of the RAP 2004 zoning found a major difference in coral trout populations on the slopes of numerous pairs of emergent and fringing reefs (Russ *et al.* 2008). Significant regional differences in the strength of this 'signal' were also measured.

At the same time, baited and towed video approaches were being developed to establish suitable indicators and sampling designs to assess the effects of the zoning plan on the fish communities of deep 'shoal' habitats inaccessible to SCUBA or extractive fish sampling techniques (Maplestone *et al.* 2006; Speare and Stowar 2007; Stowar *et al.* 2008; Johansson *et al.* 2008).

The 'deep shoal' habitats of the GBRMP are those areas where hard substrata outcrop from the seabed in deeper water (generally >20m). In contrast to emergent coral reefs they do not always form conspicuous structures, but may be either discrete or diffuse patches of hard substrata of varying relief above the surrounding sea floor. Shoal habitats are relatively unstudied but are now known to support rich and diverse fish and benthic invertebrate communities (e.g. Cappo *et al.* 2007; Pitcher *et al.* 2007).

Deep shoals are also prime areas for both recreational and commercial line fishing as they are inhabited by most of the prized table fishes in the families of snappers (Lutjanidae), cods and groupers (Serranidae) and emperors (Lethrinidae). The profusion and sophistication of electronic navigation aids and fish-finding devices, and the increased price of fuel, has focussed more intense fishing pressure on isolated 'shoal' grounds close to townships. This trend is part of a global phenomenon in the 'technological creep' of recreational fisheries (see Coleman *et al.* 2005).

The deployment of baited videos (BRUVS) by Stowar *et al.* (2008) showed strong evidence that the abundance of species prized most by recreational and commercial line fishers were, on average, approximately two times greater on a pair of southern shoals closed to fishing (green zones) relative to a pair open to fishing (blue). While the responses to zoning of the

'target' species varied in magnitude, they all showed increases. Five of these species – red emperor (*Lutjanus sebae*), red-throat emperor (*Lethrinus miniatus*), Venus tuskfish (*Choerodon venustus*), spangled emperor (*Lethrinus nebulosus*) and golden spot hogfish (*Bodianus perditio*) showed statistically significant increases. The consistency of the response of these target fishes, both individually and when aggregated in analyses, strongly suggested an effect of zoning.

That study also found varying differences in the abundance of species not caught by line-fishing in alignment with the zoning of the deep shoals. As the analyses showed no obvious trend with respect to fishing, functional groups or habitats, this result was thought to reflect natural variability in species abundance rather than the effect of zoning on these species.

The lack of known pairs of discrete, deep shoals in the southern GBRMP hampered the establishment of further comparisons, and searches based on informants and echosoundings proved both costly and fruitless. It was not possible to draw shelf-wide inferences from the two pairs of shoals sampled by Stowar *et al.* (2008).

Prized lutjanids, serranids, and lethrinids caught on 'shoals' do also inhabit the complex topography and filter-feeding epibenthic communities of deep reef bases in the 30-50m depth range. Our goal in this study was to take advantage of the knowledge gained by Russ *et al.* (2008) and Stowar *et al.* (2008) to attain as much spatial replication as possible to contrast the effects of zoning on 'shoal' species around reef bases.

We sampled around the same sixteen pairs of blue and green reefs in the Pompey, Swain and Capricorn-Bunker groups dived by Russ *et al.* (2008). We used the same, standardised protocol as that employed by Stowar *et al.* (2008) to survey deeper fish communities with the baited video technique (BRUVS).

Materials and Methods

Study area

Sixteen pairs of coral reefs open and closed to fishing were sampled as a subset of the reefs surveyed by Russ *et al.* (2008) in the southern GBRMP (Figure 1 and Appendix 1).

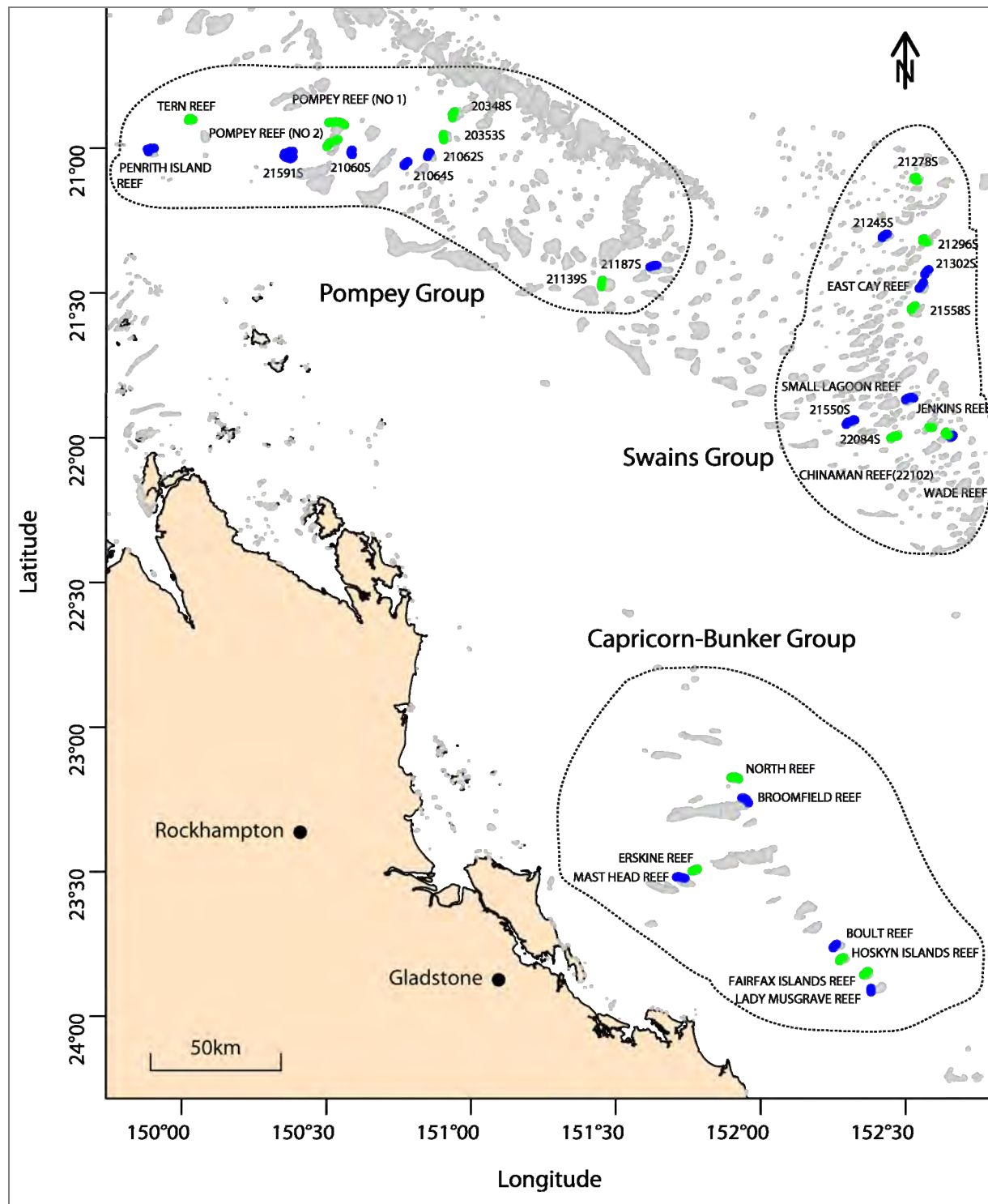


Figure 1: Location of the sixteen pairs of 'green' and 'blue' zoned reefs where BRUVS were deployed, showing the three 'reef groups' (rfgrp) used in analyses.

The shapes and sizes of the different zones in the southern GBRMP (Figure 2) enforced an imbalance in the proximity of the sixteen reef pairs to each other and to zone boundaries. In some pairs, such as Wade Reef and 22084S, 'blue' and 'green' reefs were separated only by narrow channels (Figure 2).

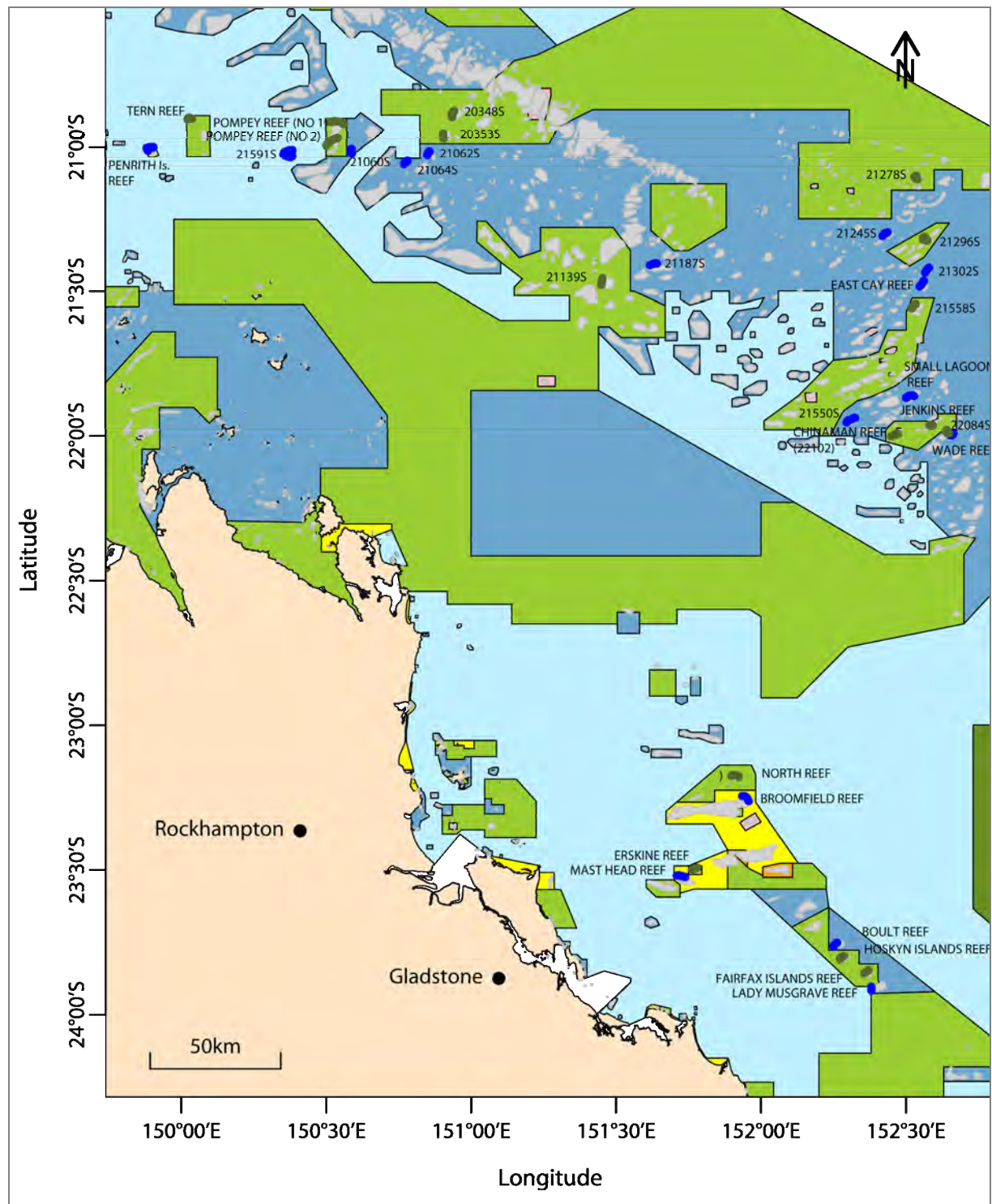


Figure 2: Location of 32 reefs where BRUVS were deployed, in relation to the prevailing zoning plan.

Fish community surveys using BRUVS

Sampling design

Sampling of the fish communities around reef bases was undertaken on a single cruise aboard the *RV James Kirby* in January-February 2009. A fleet of twelve BRUVS was deployed on the lee side of each reef.

There was no prior knowledge of either the seabed habitats or deep fish communities on the study reefs. Instead, deployments on each reef were guided by a single run of the echosounder along the depth contour (35-45m) in attempts to find the 'hard edge' of the reef where it joined the surrounding carbonate sand plain. An attempt was made to place the BRUVS about 300-450m apart on 'complex' seafloor features identified on the echosounder, but this was not always possible due to the characteristics of the reef edge and slope, the very small size of most reefs, and adverse sea conditions.

The proportion of BRUVS set in each habitat category are shown in detail in Appendices 1 and 2.

Sampling gear

The BRUVS used in this study were the standard design employed by Stowar *et al.* (2008), Speare and Stowar 2007 and Cappo *et al.* (2007) in previous surveys of inter-reefal habitats and submerged shoals.

The units consisted of a Sony Mini-DV handycam inside a simple housing made from PVC sewer pipe. This was mounted inside a pyramid-shaped galvanised steel frame that protected the camera housing, maintained a plane of view ten degrees below horizontal, and facilitated attachment of a bait arm, ballast weights and rope to the surface (Figure 3). The flexible bait arm (made of PVC conduit) held a plastic mesh bait bag containing one kilogram of crushed South Australian pilchards (*Sardinops sagax neopilchardus*) at a distance of approximately one metre in front of the camera lens.

The BRUVS frames were ballasted with steel bars according to the prevailing sea-state and current conditions to ensure stability on the seabed. An 8mm diameter polypropylene rope with surface floats attached enabled the BRUVS to be deployed and later retrieved from the surface (Figure 3). The scope of the rope was approximately twice the water depth.

Deployment and retrieval

The BRUVS were deployed by steaming along the lee side of reefs seeking the reef base and dropping the BRUVS, mooring line and buoys from the stern of the vessel. The deployment waypoint, time and depth were electronically logged into a database from a GPS at the moment of deployment. The BRUVS were then allowed to soak for one hour before they were retrieved by grappling the buoys with rope attached and winching the assembly to the surface using a hydraulic pot hauler.

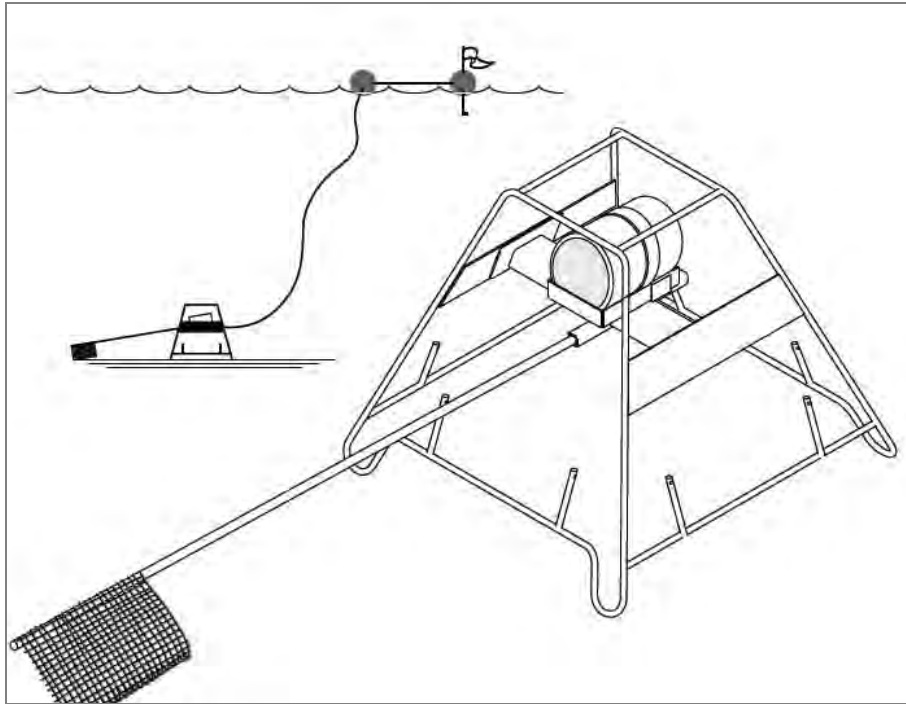


Figure 3: An AIMS Baited Remote Underwater Video Station (BRUVS). Steel ballast bars are attached to pegs on the base according to local sea surface and current conditions to prevent movement in situ.

Tape analysis

Each BRUVS deployment yielded one hour of footage of the vertebrates passing through the field of view (FOV). The footage on each tape was analysed in conjunction with the AIMS BRUVS database v2.1.04[©] (AIMS 2006 – unpublished manual). This custom built Access™ database interfaces with a video playback device to enable an operator experienced in fish taxonomy to review the footage in detail, pausing and advancing frame-by-frame where necessary using a shuttle control.

The operator captured the timing of events and made 'frame grabs' of still images as a permanent record of the benthos and species occurrences in the FOV (Figure 4). Parameters recorded in the database for each species observed included taxonomic details, time of first arrival (T_{arr}), the maximum number observed in the camera's field of view at any one time ($MaxN$) and the time that $MaxN$ occurs (T_{maxn}). Life stage (adult or juvenile), and behavioural observations (passing, feeding, chasing conspecifics, chasing other species, time of first feed) were also recorded.

Microsoft Access - [BRUVs Data Entry]

File Edit View Insert Format Records Tools Window Help

Site Data Video Images Modify Images Controls

Op_Code: RAPWwba Camera: 1 Reader: Marcus Stowar Time In: 13/02/2007 3:30:37 PM Time on Seabed: 1.31666 Time Bait Gone: End of Sampling: 62.53333

Family	Genus	Species
Chaetodontidae	Chaetodon	lunulatus
Pomacanthidae	Centropyge	tibicen
Acanthuridae	Naso	annulatus
Lutjanidae	Lutjanus	adeti
Chaetodontidae	Coradion	altivelis
Labridae	Choerodon	venustus
Chaetodontidae	Heniochus	acuminatus
Serranidae	Plectropomus	leopardus
Chaetodontidae	Chaetodon	rainfordi
Lethrinidae	Gymnocranius	audleyi
Serranidae	Epinephelus	fasciatus

Record: 4 of 35

Time First Seen: 1.38333 Stage: AD Activity: F Time First Feed: 4.26666 Max Num: 100 Time Max Num: 1.43333 CAAB Code: 37346033

Buttons: Bait Gone, First Appearance, JUV, ADU, Feeding, Scavenging, Passing, Chase Consp, Chase Other, Time Max Num, Cap Fish Image, End of Sampling, Delete Fish

Comments: coral. Vis 10m. Numerous unidentifiable small reef dwelling fishes.

Buttons: Show Fish Img, Show Ref Img, Show Benthos Img, Marked Fish, All Images of Fish, All Fish from Camera, All Fish from Site, Import Image, Stills of Fish, Stills in Time

Microsoft Access - [BRUVs Data Entry]

File Edit View Insert Format Records Tools Window Help

Site Data Video Images Modify Images Controls

Lutjanus sebae

Buttons: Lutjanidae, Lutjanus, sebae, Ref Images for taxa, All Images for Taxa, Clear, Move To Record, Delete Image, Make Ref Image, (Un)Mark Image, Modify Image

1 to 12 of 14

Navigation arrows: ← →

Figure 4: Screen grabs from the AIMS BRUVS 2.1.04 video interface showing the main entry form and an example of reference imagery for the red emperor *Lutjanus sebae*.

Habitat classification

The benthic habitat within the field of view of each BRUVS was categorised during the tape reading process. Estimates were made of percentage cover (to the nearest ten percent) of abiotic substratum types and also major epibenthos. In addition, one of five habitat categories was assigned to each sample based on the composition of the substratum and epibenthic communities (Table 1).

Table 1: Habitat variables recorded in conjunction with BRUVS deployments.

Variable	Definition
Composition of underlying substratum	<i>(Estimated from BRUVS field of view as percentage cover of each component of following types, to nearest ten percent)</i> SAND RUBBLE CONSOLIDATED OUTCROP OR REEF
Composition of epibenthic community	<i>(Estimated from BRUVS field of view as percentage cover of each component of the following types, to nearest ten percent)</i> HARD CORAL SOFT CORAL SPONGE MACROALGAE WHIPS AND GORGONIANS ENCRUSTING ORGANISMS BARE SUBSTRATUM
Habitat category	<i>(Category allocated based on overall habitat within the BRUVS field of view)</i> OPEN SANDY SEABED ALGAL MEADOW GORGONIAN and SEAWHIP GARDEN CORAL DOMINATED REEF LOW RELIEF RUBBLE FIELD
Deployment position	<i>(Recorded as ship's GPS position at deployment)</i> LATITUDE LONGITUDE
Depth	<i>(Recorded from ship's depth sounder at deployment)</i>

Data treatment and analysis

Fish abundances were analysed using generalised linear mixed-effect (GLME) models using the R statistical package (R Development Core Team 2006).

Generalised linear mixed-effects models

The GLME models assessed differences in fish *MaxN* values between the reef bases zoned green (closed to fishing) and blue (open to fishing) while accounting for potential differences in habitat, reef group and depth. The skewed distribution of counts, characteristic of BRUVS data, required the use of a negative binomial distribution and a log link as the observed variance was multiple times greater than the mean of all fish groups. Detail on the analyses and the rationale behind them is provided in the results section

Explanatory variables

Although the pairs of reefs were matched as closely as possible for all characteristics other than zoning by Russ *et al.* (2008), explanatory variables considered likely to contribute to fish community differences between the reef bases, other than zoning, were also incorporated into the analysis.

The explanatory variables used in this study were (names or acronyms in parentheses give the short form used in model descriptions):

1. Zone: **Green** or **Blue** (G, b);
2. Reef Group: **Pompeys, Swains and Capricorn-Bunkers** (rfgrp)
3. Habitat class: A categorical variable with four classes (labelled 'CORAL DOMINATED REEF', 'GORGONIAN and SEAWHIP GARDEN', 'LOW RELIEF RUBBLE FIELD', 'ALGAL MEADOW', or 'OPEN SANDY SEABED') (habcat); and
4. Depth (m): As a continuous predictor

The response variables were based on the maximum number of fish (of any given species) sighted at once in the field of view from each BRUVS deployment (*MaxN*). This was assumed to be a conservative index of local abundance and is comparable within and amongst species and reefs (see Cappo *et al.* 2003, 2004 for reviews of *MaxN*).

'Target', 'bycatch' and 'unfished' species

Fish, sharks, rays and seasnakes are hereafter referred to as 'fish'. For the purposes of assessing the possible direct and indirect effects of reef zoning, fish species were categorised in three sub-sets depending on the likelihood they would be caught and retained by line fishers. The three categories were:

- i. '*Target species*' (Table 1): These 21 species included the most desirable demersal fishes based on their market price and size, as well as their reef dwelling habits.
- ii. '*Bycatch species*' (Table 5): These 85 species included the ('undersized') juveniles of species in category (i) as well as the undesirable fishes caught by line fishers. Pelagic and semi-pelagic species (e.g. carangid trevallies and scombrid mackerels) were placed in this category, as were smaller lutjanid snappers and lethrinid emperors that are retained for consumption or use as bait, or are released alive. All sharks and rays likely to take a baited hook were placed in this category.

- iii. '*Unfished species*' (Table 6): These 251 species included all those unlikely to be hooked because of their dietary preferences (e.g. scarid herbivores, chaetodontid butterflyfishes) or small size (e.g. pomacentrid damselfishes).

The aggregated sum of all categories ('*all species*') was used in some analyses as a fourth category.

Although there was some degree of subjectivity in such a classification, the rationale for analysing the community data in this manner was to distinguish amongst species in terms of their vulnerability to fishing, and their likelihood of retention if caught by line fishers. The effects of zoning may vary amongst the different categories.

Results

Habitats sampled in green and blue reefs within the sixteen reef pairs

Four of the five habitat categorisations were amalgamated into 'complex' ('CORAL DOMINATED REEF' + 'GORGONIAN and SEAWHIP GARDEN') and 'simple' ('ALGAL MEADOW' + 'OPEN SANDY SEABED') habitat types in Figure 5 and Figure 6. These figures, and Table 2, show that sampling of 'complex' habitat types generally thought to support highly-prized target species was not matched consistently between reefs within pairs.

The imbalances in the ratio of BRUVS replicates categorised as 'complex' habitat between green and blue reefs in each pair of reefs are also shown in Appendices 1 and 2 and Tables 2 and 3. 'Habitat' was therefore considered to be a major, random variable in analyses of fish abundance.

Table 2: The number of BRUVS sets categorised by the seabed in the in the field of view according to five categories. There were inconsistencies amongst the three reef groups in the amount and nature of 'favourable' habitat for demersal species.

Count of BRUVS sets	OPEN SANDY SEABED	ALGAL MEADOW	LOW RELIEF RUBBLE FIELD	GORGONIAN and SEAWHIP GARDEN	CORAL DOMINATED REEF
All Blue reefs	41	10	55	40	41
All Green reefs	45	23	51	42	26
Pompey group	22	3	31	47	34
Swain group	37	20	34	25	25
Cap-Bunk group	27	10	41	10	8

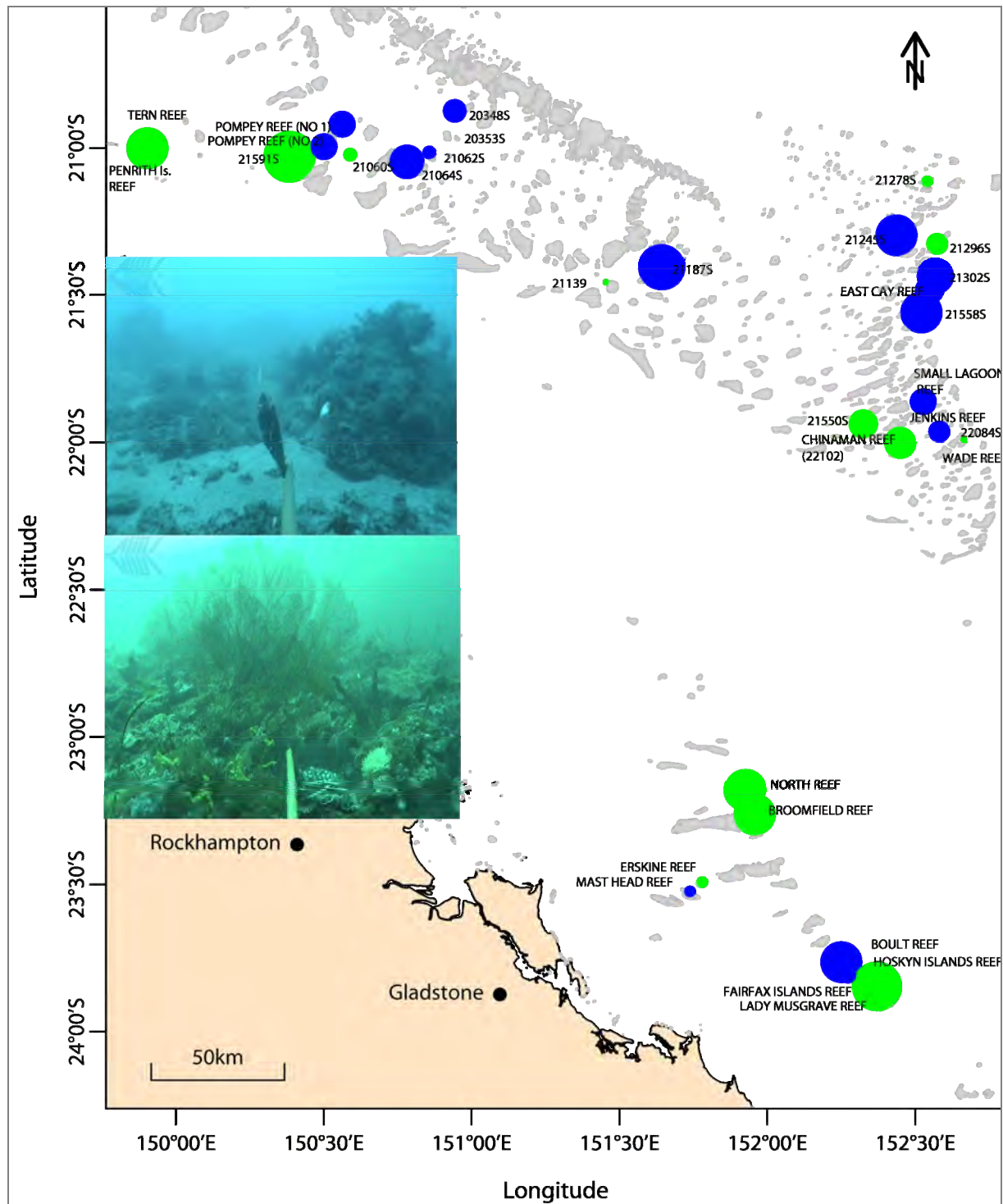


Figure 5: Proportion of BRUVS sets on each reef classified as 'coral dominated' or 'gorgonian and sea whip gardens'. These were recognised as 'complex habitats' thought to be preferred by prized target species.

Ratios of 'target', 'bycatch' and 'unfished' groups between green and blue reefs within the sixteen reef pairs

Coarse ratios of *MaxN* in Table 3 and Figures 7 to 8 appear to show that both 'target' and 'bycatch' species were more abundant in the green reefs of about half the reef pairs, and these were not always the reef pairs where there was more 'complex' habitat in the green reef BRUVS replicates. Most of the green reefs had more 'unfished' species than the blue reefs within pairs (Figure 9).

Table 3: Summaries of habitat and fish categorisation of BRUVS data in the sixteen pairs (rf.pair) of reef bases open and closed to fishing in the Pompey, Swain and Capricorn-Bunker groups (rf.grp) of reefs in the southern GBRMP. The reef pair number follows Russ *et al.* (2008). The number of BRUVS sets classified by habitat categories within reefs as gorg (GORGONIAN and SEAWHIP GARDEN), and corl.dom (CORAL DOMINATED REEF) were summed and divided by the number of replicates at each reef as an index of 'habitat complexity'. The indices for each reef within a pair were expressed as hab.ratio (Green:Blue). The ratio (Green:Blue) of the total number ($\Sigma MaxN$) of fishes, sharks and rays classified as tar.ratio (PRIZED TARGETS), byc.ratio (BYCATCH) and unf.ratio (UNFISHED) are shown. The same ratio for pooled categories is shown as allf.ratio (ALL SPECIES). For example, reef pair 14 in the Pompey group had the same amount of BRUVS sets in 'complex habitat' in both blue and green zones, but there were 2.86 times more 'prized' fish counted in the green zone.

rf.pair	rf.grp	hab.ratio	tar.ratio	byc.ratio	unf.ratio	allf.ratio
13	Pompeys	1.67	0.03	0.25	5.44	3.36
14	Pompeys	1	2.86	2.23	1.96	2.13
15	Pompeys	0.37	1.97	1.26	4.55	3.1
16	Pompeys	1.11	0.78	1.25	0.48	0.68
17	Pompeys	1	1.31	1.82	1.86	1.75
18	Pompeys	1.2	2.15	1.2	2.2	1.95
19	Swains	0.2	0.38	0.64	1.12	0.8
20	Swains	0.67	1.67	0.98	1.03	1.05
21	Swains	0.4	0.59	1.07	0.76	0.81
22	Swains	0.43	0.86	0.72	0.73	0.74
23	Swains	1.83	1.4	1.43	0.37	0.63
24	Swains	1	1.16	0.84	1.58	1.27
25	Cap-Bunks	1.2	1.81	0.57	2.46	1.7
26	Cap-Bunks	0	0.24	1.74	0.68	0.74
27	Cap-Bunks	0.25	0.31	0.32	1.96	1.13
28	Cap-Bunks	NA	0.16	0.98	1.42	1.31

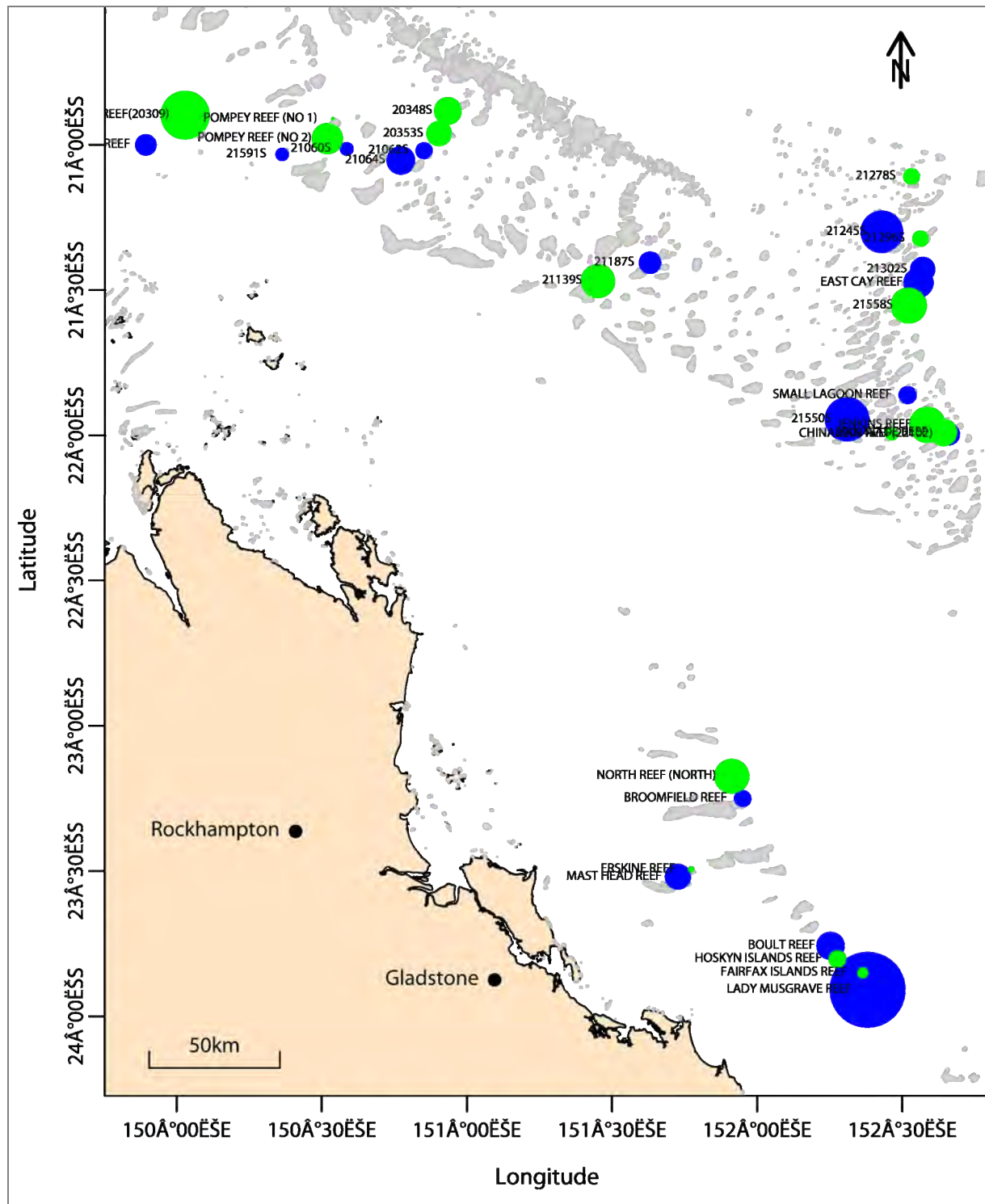


Figure 7: Reefs scaled by the summed abundance ($\Sigma MaxN$) of all 'target' species sighted on BRUVS.

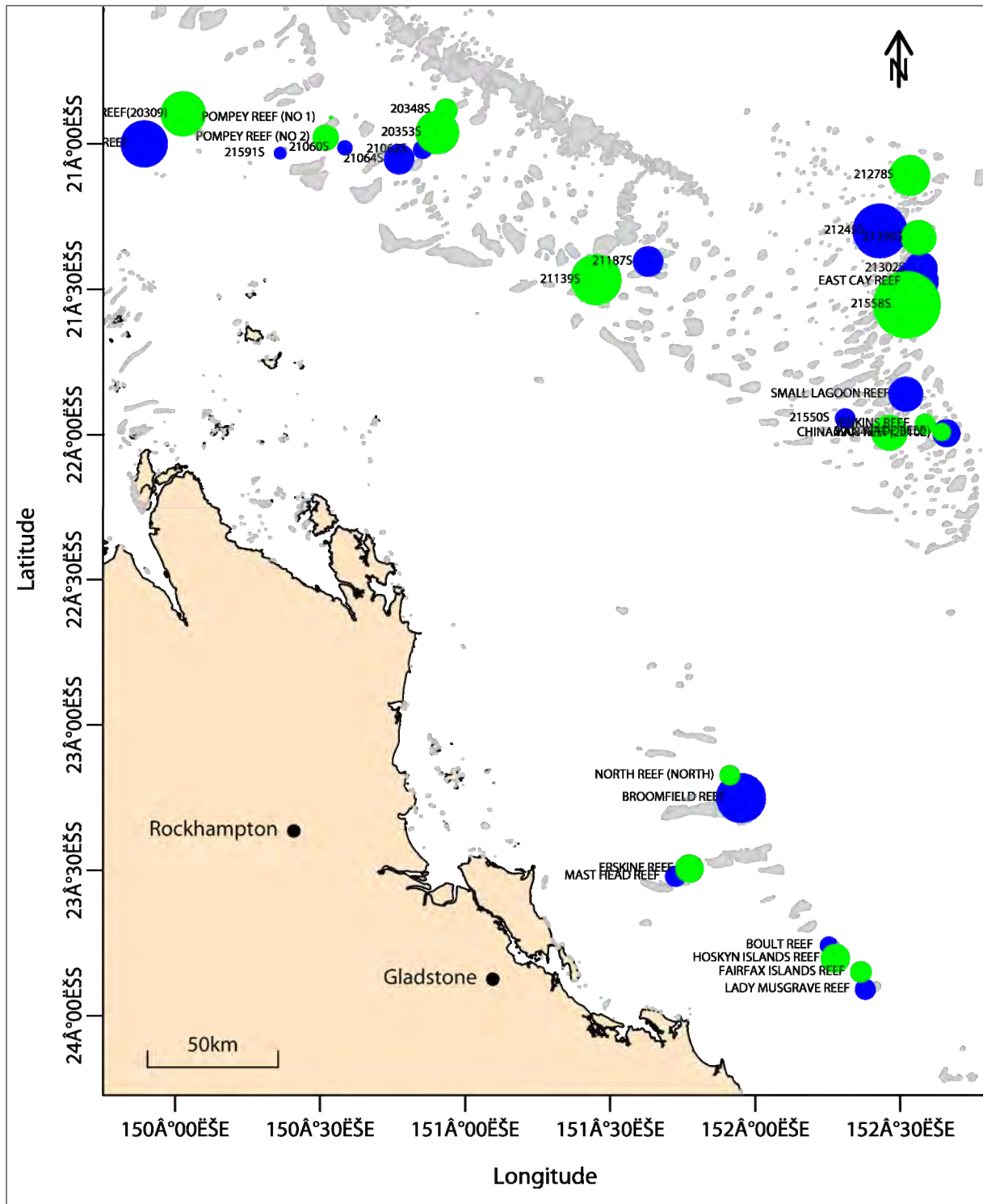


Figure 8: Reefs scaled by the summed abundance ($\sum MaxN$) of all 'bycatch' species sighted on BRUVS.

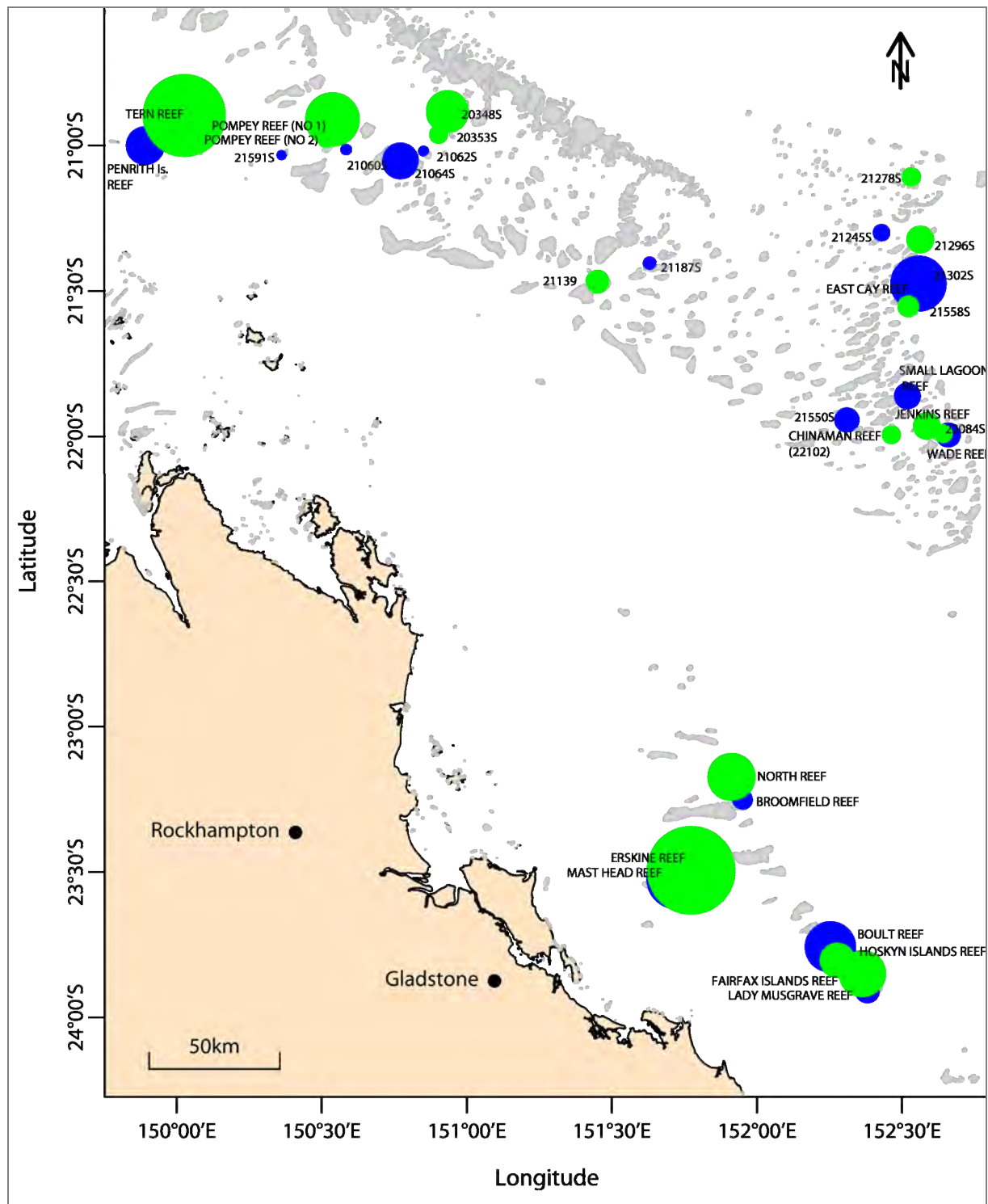


Figure 9: Reefs scaled by the summed abundance ($\Sigma MaxN$) of all 'unfished' species sighted on BRUVS.

Ratios of 'target' and 'bycatch' species between green and blue reefs within the sixteen reef pairs

The coarse ratios in *MaxN* of key target species showed no consistently higher trend for increases in green zones (Table 4). There appeared to be higher *MaxN* of coral trout (Figure 10), red emperor (Figure 11) and red-throat emperor (Figure 12) in green reefs of the Pompey group, but the Swain and Capricorn-Bunker groups did not show the same trend. The highly prized Venus tuskfish showed no trend for increased *MaxN* in green reefs of any of the reef groups (Figure 13).

The trends in *MaxN* of bycatch species between zones were also inconsistent (Table 5), with the exception of Chinaman fish (Figure 14), which had values of *MaxN* consistently twice as abundant around green reefs. The *MaxN* of grey reef sharks (Figure 15) was higher around the green reefs of the Pompey and Swain groups.

Target and bycatch species generally had lowest *MaxN* around the Capricorn-Bunker reefs, and white-tip reef sharks (Figure 16) were not recorded there in green zones.

There was wide variation amongst zones and reef groups in the *MaxN* of 'unfished' species (Table 6), but it was notable that the *MaxN* of *Pentapodus paradiseus* and *Pentapodus nagasakiensis* were much higher around green reefs. Generally the *MaxN* of unfished species were similar around blue and green reefs within reef groups.

The general trends emerging prior to modelling indicated strong effects and interactions of reef zones, reef groups and habitat types, with evidence that the pairs in the Capricorn-Bunker Group were the most similar.

Table 4: Summary of 1,703 sightings ($\Sigma MaxN$) of 21 'target' species (adults AD) on BRUVS tapes in the reefs open (b) and closed to fishing (G) in the three reef groups. The ratio of overall numbers in the two types of zones is shown as G:b.

family	sci.name	$\Sigma MaxN$	Pompeys		Swains		Cap-Bunks		G:b
			G	b	G	b	G	b	
Haemulidae	<i>Diagramma pictum</i> AD	82	8	9	28	10	10	17	1.28
Labridae	<i>Bodianus perditio</i> AD	2	0	0	0	0	1	1	1
	<i>Choerodon schoenleinii</i> AD	16	3	5	0	0	4	4	0.78
	<i>Choerodon venustus</i> AD	637	115	141	126	110	61	84	0.9
Lethrinidae	<i>Lethrinus laticaudis</i> AD	2	0	2	0	0	0	0	-
	<i>Lethrinus miniatus</i> AD	281	64	41	48	58	35	35	1.1
	<i>Lethrinus nebulosus</i> AD	71	20	22	14	5	5	5	1.22
	<i>Lethrinus olivaceus</i> AD	20	14	0	3	1	0	2	5.67
Lutjanidae	<i>Aprion virescens</i> AD	31	3	0	8	6	0	14	0.55
	<i>Lutjanus malabaricus</i> AD	1	1	0	0	0	0	0	-
	<i>Lutjanus sebae</i> AD	132	44	20	28	15	10	15	1.64
Rachycentridae	<i>Rachycentron canadum</i> AD	3	0	0	0	3	0	0	-
Serranidae	<i>Cephalopholis sonnerati</i> AD	1	1	0	0	0	0	0	-
	<i>Epinephelus coioides</i> AD	3	0	1	0	0	1	1	0.5
	<i>Epinephelus malabaricus</i> AD	2	0	2	0	0	0	0	-
	<i>Epinephelus undulatostratus</i> AD	3	0	0	0	0	1	2	0.5
	<i>Plectropomus laevis</i> AD	5	0	2	0	3	0	0	-
	<i>Plectropomus leopardus</i> AD	389	129	85	32	85	16	42	0.83
	<i>Plectropomus maculatus</i> AD	1	0	1	0	0	0	0	-
	<i>Variola albimarginata</i> AD	4	0	0	0	0	1	3	0.33
	<i>Variola louti</i> AD	17	0	0	1	1	8	7	1.12

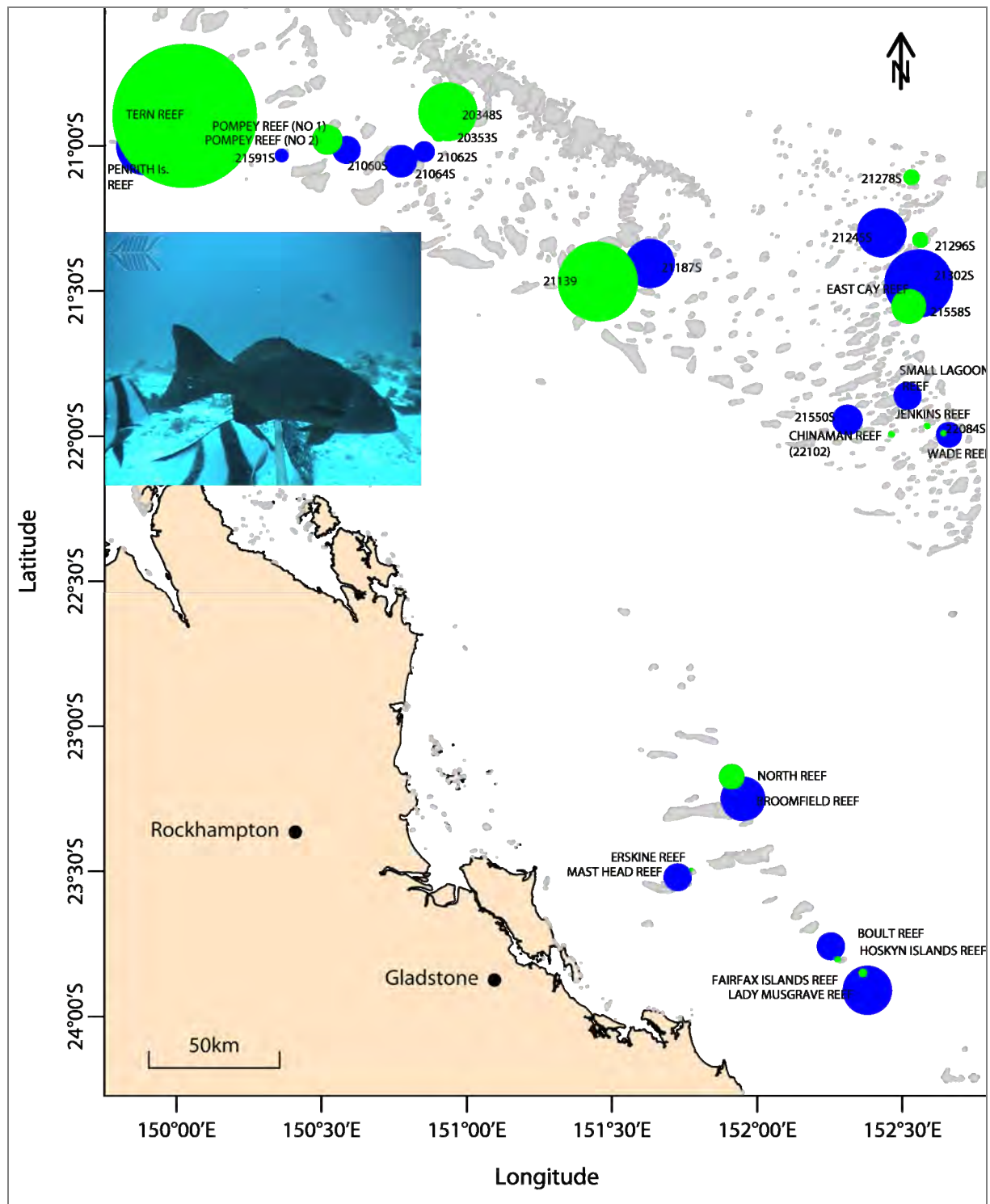


Figure 10: Reefs scaled by the summed abundance ($\Sigma MaxN$) of 389 coral trout sighted on BRUVS.

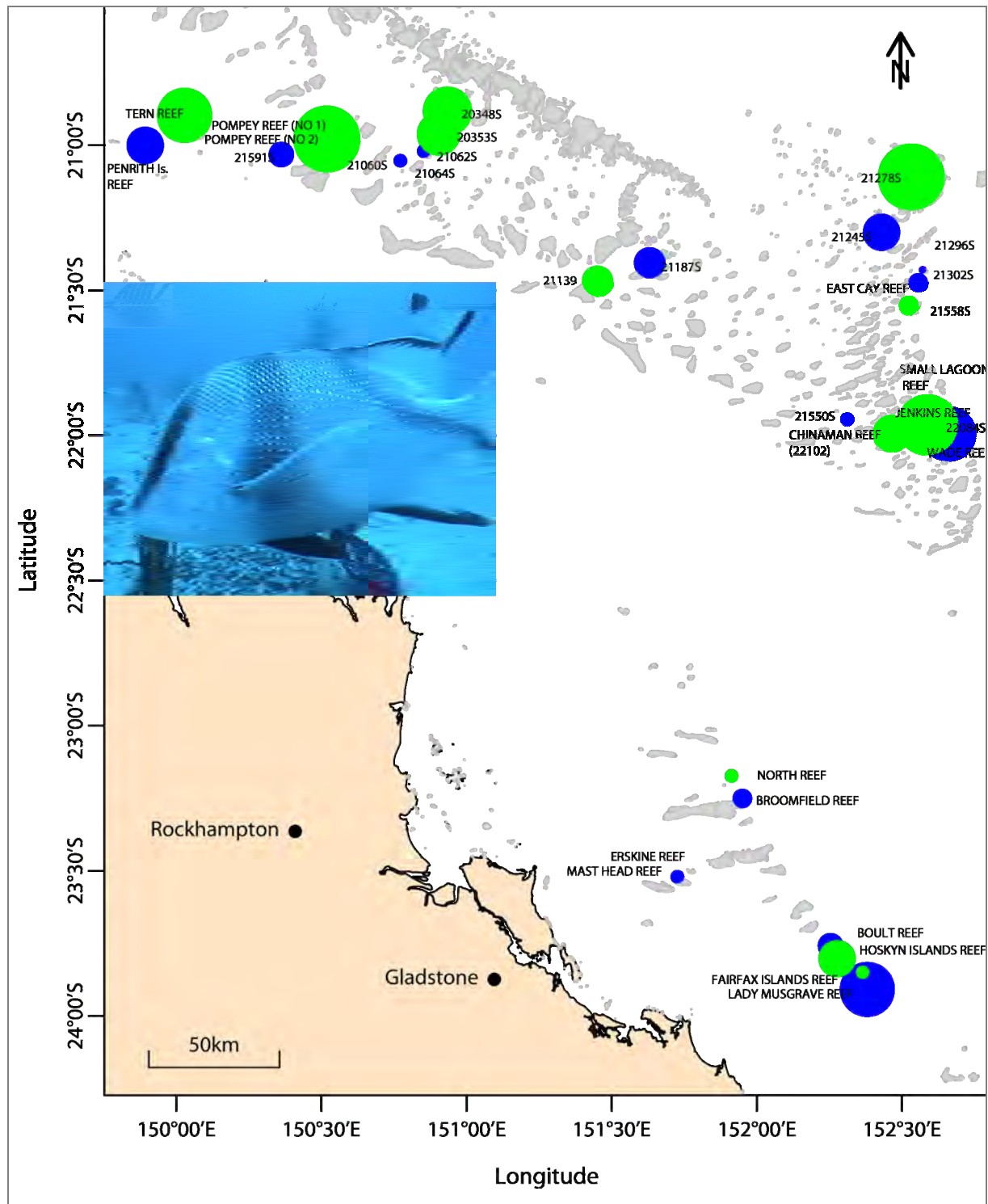


Figure 11: Reefs scaled by the summed abundance ($\Sigma MaxN$) of 132 red emperor sighted on BRUVS.

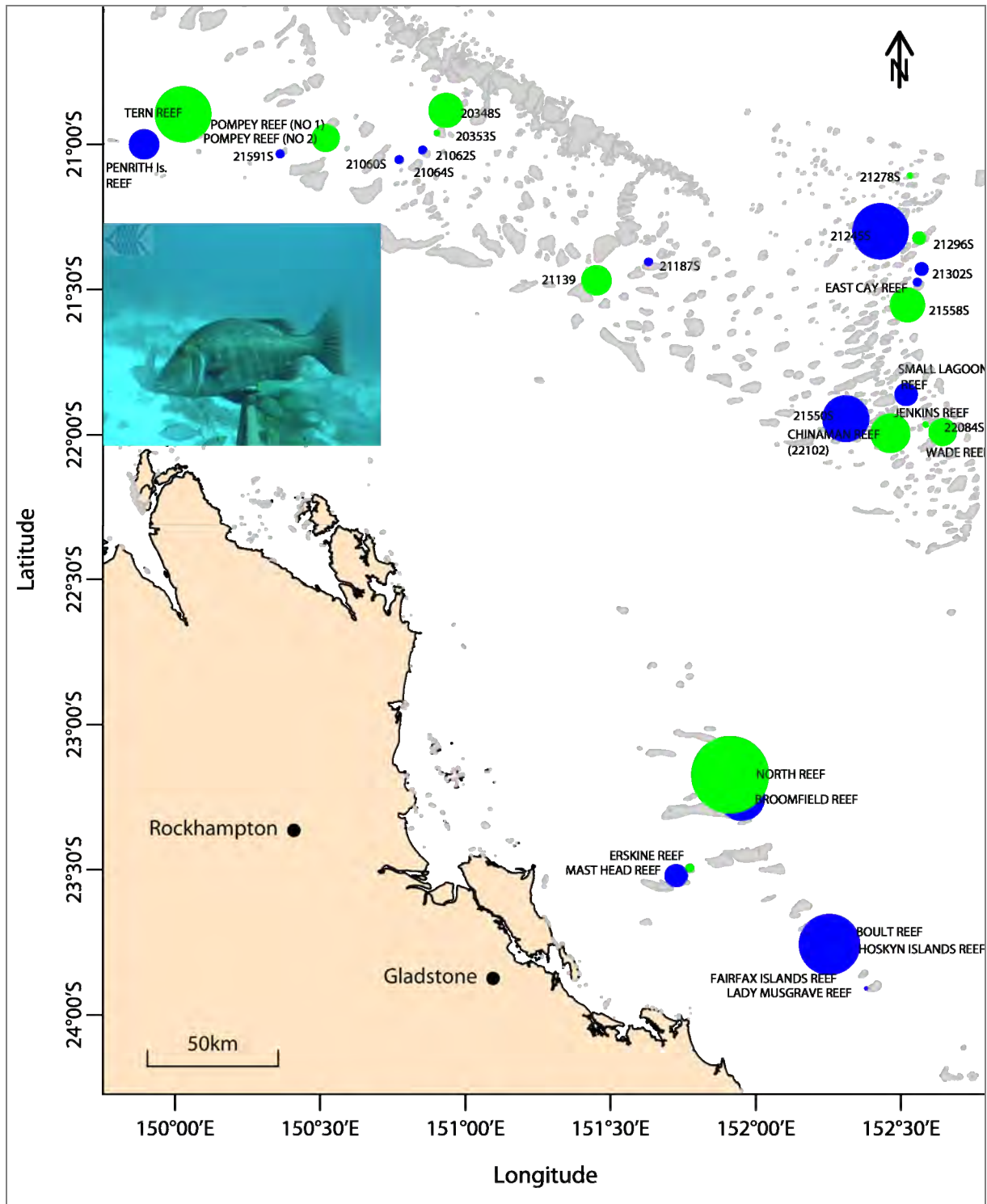


Figure 12: Reefs scaled by the summed abundance ($\Sigma MaxN$) of 281 red-throat emperor sighted on BRUVS.

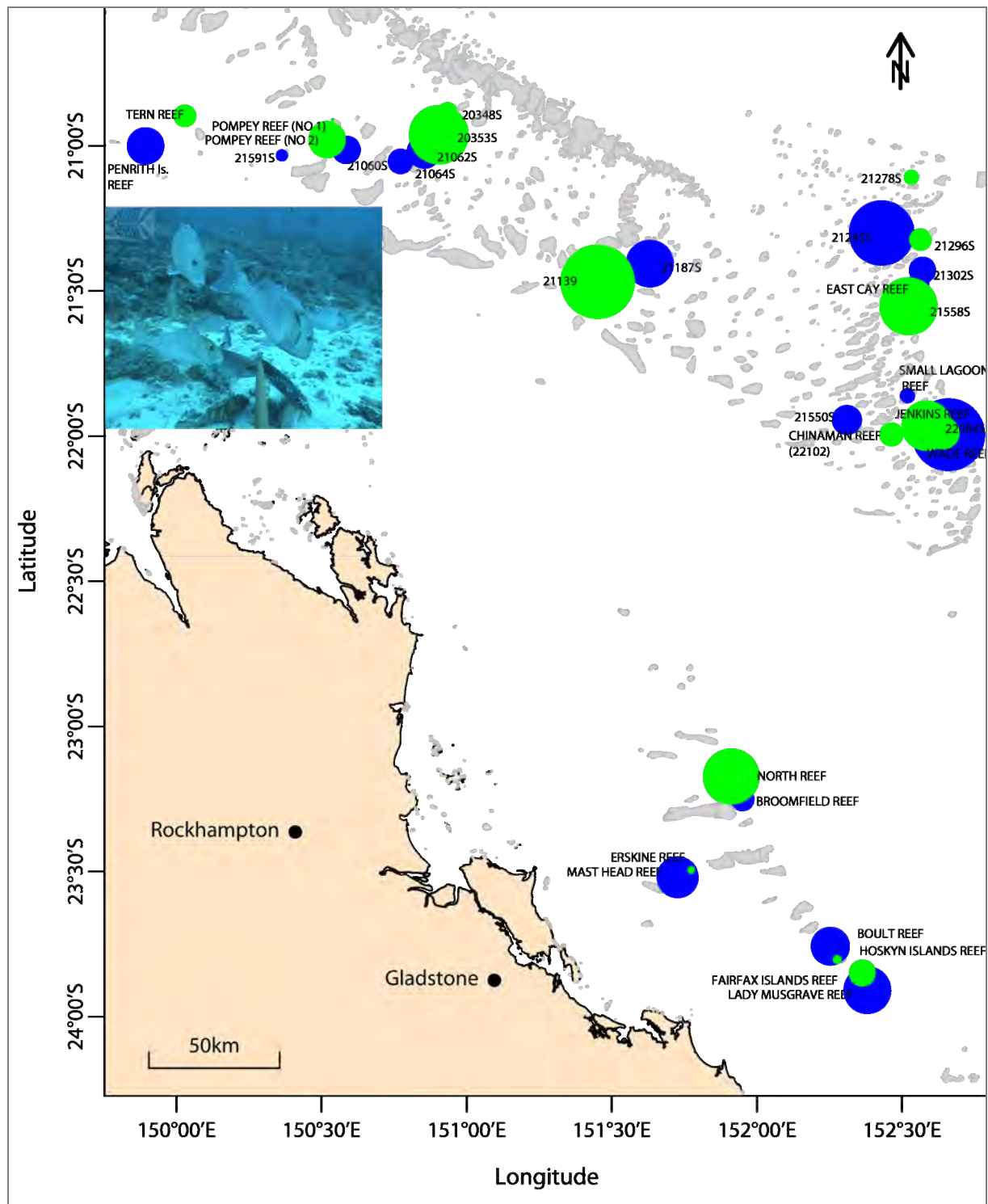


Figure 13: Reefs scaled by the summed abundance ($\sum MaxN$) of 637 Venus tusk fish sighted on BRUVS.

Table 5: Summary of sightings (ΣMaxN) of the major 'bycatch species' (adult AD and juvenile JUV) on BRUVS tapes in the reefs open (b) and closed to fishing (G) in the three reef groups. The ratio of overall numbers in the two types of zones is shown as G:b. Only those 37 species occurring on at least six BRUVS sets are shown. A total of 5,510 individuals of 85 species comprised the 'bycatch' category.

family	sci.name	ΣMaxN	Pompeys		Swains		Cap-Bunks		G:b
			G	b	G	b	G	b	
Carangidae	<i>Carangoides chrysophrys</i> AD	31	16	15	0	0	0	0	1.07
	<i>Carangoides fulvoguttatus</i> AD	512	111	90	78	83	61	89	0.95
	<i>Carangoides fulvoguttatus</i> JUV	163	62	52	8	37	0	4	0.75
	<i>Carangoides gymnotethus</i> AD	136	19	36	6	19	24	32	0.56
	<i>Carangoides gymnotethus</i> JUV	102	22	5	50	23	1	1	2.52
	<i>Caranx ignobilis</i> AD	8	4	1	3	0	0	0	7
	<i>Gnathanodon speciosus</i> AD	12	2	0	9	1	0	0	11
	<i>Gnathanodon speciosus</i> JUV	122	56	27	35	1	0	3	2.94
	<i>Pseudocaranx dentex</i> AD	20	0	0	9	7	2	2	1.22
Carcharhinidae	<i>Carcharhinus albimarginatus</i> AD	14	2	0	4	5	0	3	0.75
	<i>Carcharhinus amblyrhynchos</i> AD	102	49	16	15	15	1	6	1.76
	<i>Carcharhinus amblyrhynchos</i> JUV	35	19	3	8	5	0	0	3.38
	<i>Galeocerdo cuvier</i> AD	8	3	2	0	0	2	1	1.67
	<i>Triaenodon obesus</i> AD	21	8	3	4	6	0	0	1.33
Ginglymostomatidae	<i>Nebrius ferrugineus</i> AD	6	4	1	1	0	0	0	5
Hemiscylliidae	<i>Chiloscyllium punctatum</i> AD	28	2	4	5	1	4	12	0.65
Labridae	<i>Choerodon cyanodus</i> AD	18	15	3	0	0	0	0	5
	<i>Choerodon fasciatus</i> AD	26	9	7	5	5	0	0	1.17
	<i>Choerodon venustus</i> JUV	60	30	13	4	11	2	0	1.5
Lethrinidae	<i>Gymnocranius audleyi</i> AD	1053	239	341	133	122	99	119	0.81
	<i>Gymnocranius grandoculis</i> AD	7	0	0	7	0	0	0	-
	<i>Lethrinus genivittatus</i> AD	249	5	0	1	13	196	34	4.3
	<i>Lethrinus ravus</i> AD	266	66	55	57	62	26	0	1.27
	<i>Lethrinus rubrioperculatus</i> AD	30	0	0	16	4	6	4	2.75
	<i>Lethrinus semicinctus</i> AD	1286	178	181	433	471	14	9	0.95
Lutjanidae	<i>Lutjanus adetii</i> AD	553	44	46	146	157	10	150	0.57
	<i>Lutjanus carponotatus</i> AD	40	21	9	3	6	0	1	1.5
	<i>Lutjanus vitta</i> AD	65	23	24	3	15	0	0	0.67
	<i>Symphorus nematophorus</i> AD	130	36	14	23	13	31	13	2.25
	<i>Symphorus nematophorus</i> JUV	12	1	1	5	5	0	0	1
Rhynchobatidae	<i>Rhynchobatus djiddensis</i> AD	9	1	1	5	0	2	0	8

family	sci.name	$\Sigma MaxN$	Pompeys		Swains		Cap-Bunks		G:b
			G	b	G	b	G	b	
Scombridae	<i>Gymnosarda unicolor AD</i>	23	0	4	0	17	0	2	-
	<i>Scomberomorus commerson AD</i>	28	4	8	3	1	4	8	0.65
Serranidae	<i>Cephalopholis boenak AD</i>	14	2	8	0	3	0	1	0.17
	<i>Epinephelus fasciatus AD</i>	12	1	3	0	0	0	8	0.09
	<i>Epinephelus quoyanus AD</i>	6	4	0	0	0	0	2	2
	<i>Plectropomus leopardus JUV</i>	24	10	11	0	3	0	0	0.71

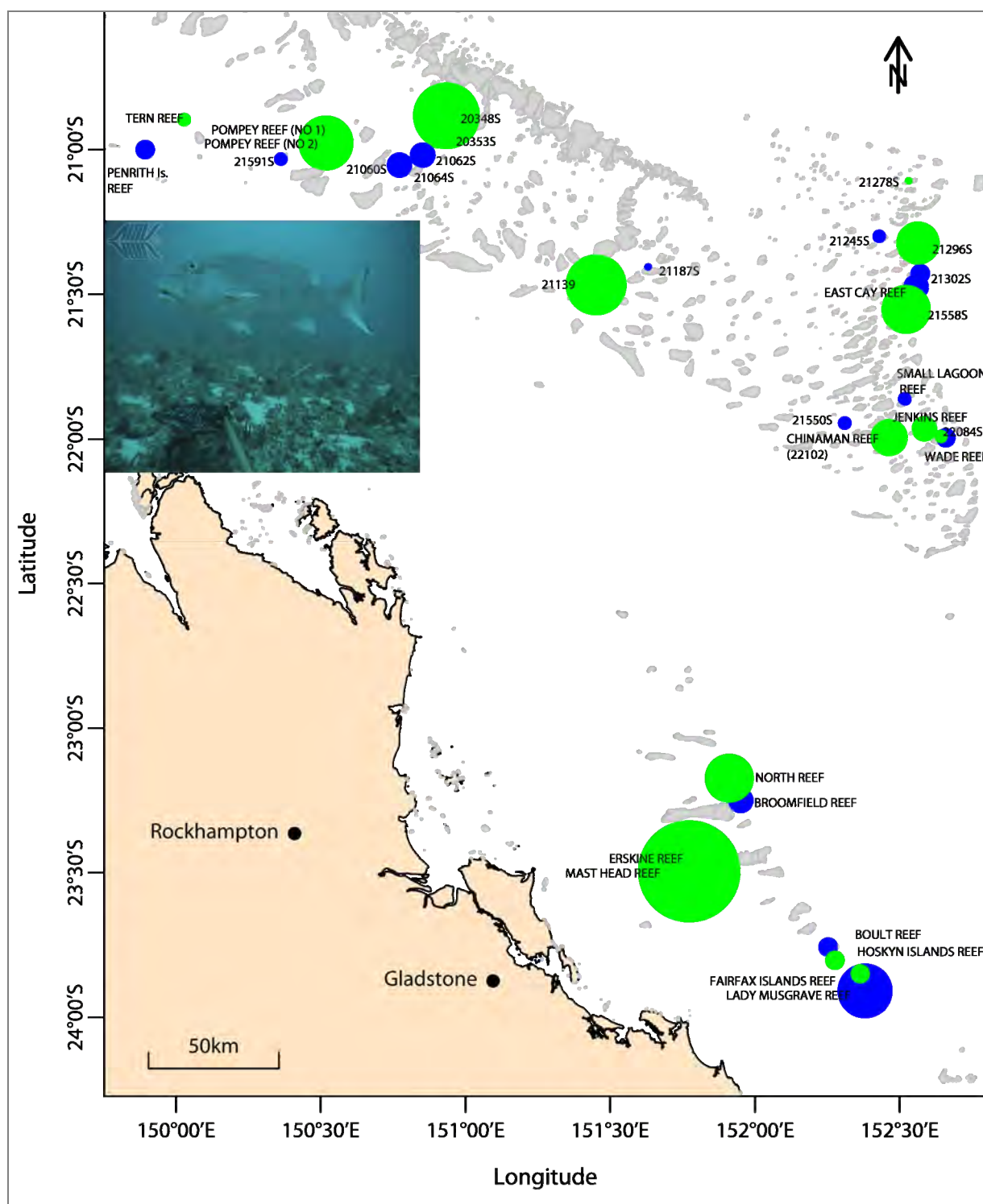


Figure 14: Reefs scaled by the summed abundance ($\Sigma MaxN$) of 130 Chinaman fish (*Symphorus nematophorus*) sighted on BRUVS. This long-lived species is commonly hooked as bycatch by line fishers fishing for red emperor. It is now declared as 'no take' under Queensland fisheries legislation because of rumours about ciguatoxic properties of the flesh.

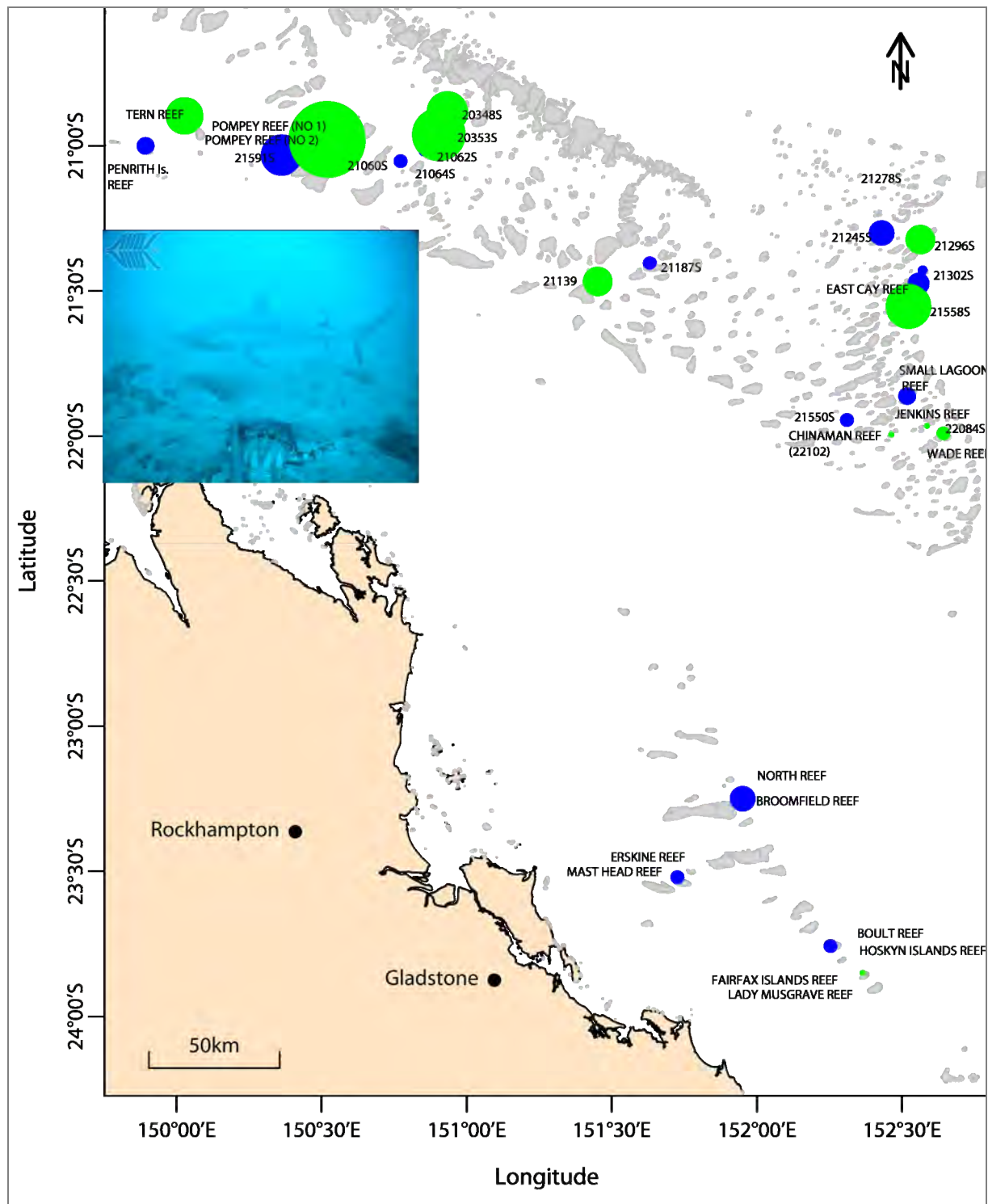


Figure 15: Reefs scaled by the summed abundance ($\sum MaxN$) of 137 adult and juvenile grey reef sharks sighted on BRUVS. All life stages of this species are hooked as bycatch by line fishers.

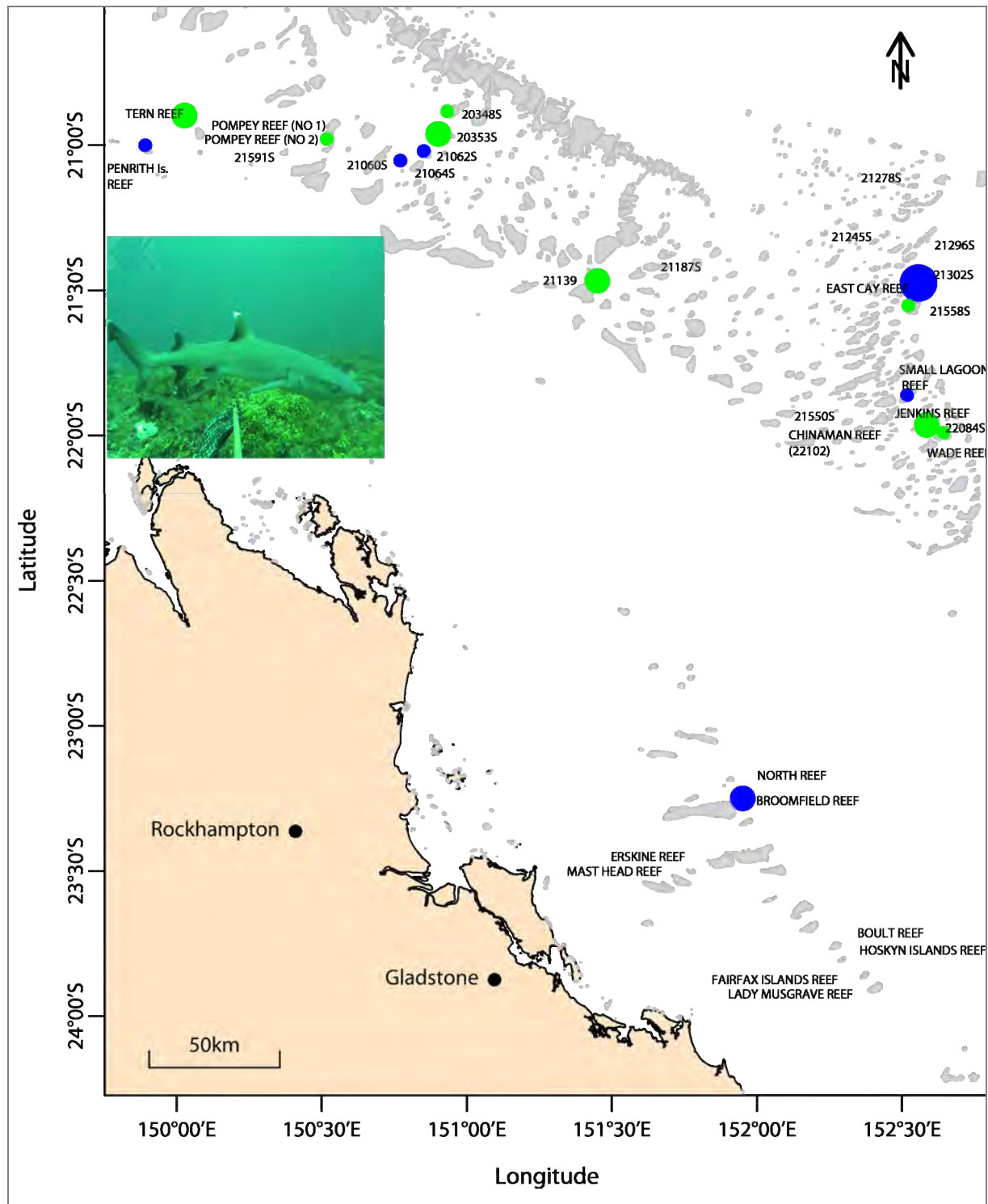


Figure 16: Reefs scaled by the summed abundance ($\sum MaxN$) of 21 white-tip reef sharks sighted on BRUVS. This species is hooked as bycatch by line fishers.

Table 6: Summary of sightings (ΣMaxN) of the major 'unfished species' on BRUVS tapes in the reefs open (b) and closed to fishing (G) in the three reef groups. The ratio of overall numbers in the two types of zones is shown as G:b. Only those 42 species occurring on at least twenty BRUVS sets are shown. A total of 16,635 individuals of 251 species comprised the 'unfished' category.

family	sci.name	ΣMaxN	Pompeys		Swains		Cap-Bunks		G:b
			G	b	G	b	G	b	
Acanthuridae	<i>Acanthurus dussumieri</i> AD	85	2	6	8	23	21	25	0.57
Balistidae	<i>Abalistes stellatus</i> AD	529	127	142	55	50	94	61	1.09
	<i>Sufflamen fraenatum</i> AD	125	4	2	32	32	17	38	0.74
Caesionidae	<i>Caesio cuning</i> AD	459	296	98	29	22	0	14	2.43
	<i>Pterocaesio marri</i> AD	1274	660	250	130	213	8	13	1.68
Chaetodontidae	<i>Chaetodon rainfordi</i> AD	36	4	12	1	14	0	5	0.16
	<i>Chelmon rostratus</i> AD	39	13	11	5	8	0	2	0.86
	<i>Coradion altivelis</i> AD	83	15	18	14	16	4	16	0.66
Echeneidae	<i>Echeneis naucrates</i> AD	77	21	10	9	10	9	18	1.03
Grammistidae	<i>Diploprion bifasciatum</i> AD	34	6	4	6	8	2	8	0.7
Labridae	<i>Cheilinus fasciatus</i> AD	46	13	9	5	17	0	2	0.64
	<i>Choerodon gomoni</i> AD	85	0	0	31	30	21	3	1.58
	<i>Choerodon jordani</i> AD	106	27	8	9	12	26	24	1.41
	<i>Choerodon vitta</i> AD	90	31	32	13	12	1	1	1
	<i>Cirrhilabrus punctatus</i> AD	533	134	199	28	114	4	54	0.45
	<i>Coris pictoides</i> AD	38	2	4	6	14	12	0	1.11
	<i>Halichoeres zeylonicus</i> AD	62	2	0	33	18	2	7	1.48
	<i>Labroides dimidiatus</i> AD	125	23	18	15	29	12	28	0.67
	<i>Leptojulis cyanopleura</i> AD	484	130	52	29	41	107	125	1.22
	<i>Oxycheilinus bimaculatus</i> AD	154	5	3	41	25	74	6	3.53
	<i>Oxycheilinus digrammus</i> AD	35	6	16	1	12	0	0	0.25
	<i>Suezichthys devisi</i> AD	60	2	3	13	13	5	24	0.5
Mullidae	<i>Parupeneus barberinoides</i> AD	41	2	3	8	8	11	9	1.05
	<i>Parupeneus barberinus</i> AD	47	4	18	2	13	5	5	0.31
	<i>Parupeneus heptacanthus</i> AD	206	34	41	40	43	20	28	0.84
Nemipteridae	<i>Pentapodus aureofasciatus</i> AD	670	100	85	97	187	76	125	0.69
	<i>Pentapodus nagasakiensis</i> AD	2716	157	69	832	469	757	432	1.8
	<i>Pentapodus paradiseus</i> AD	320	139	84	2	3	80	12	2.23
	<i>Scolopsis monogramma</i> AD	92	12	22	1	6	16	35	0.46
Pinguipedidae	<i>Parapercis xanthozona</i> AD	76	13	11	9	13	14	16	0.9
Pomacanthidae	<i>Chaetodontoplus meredithi</i> AD	145	26	33	15	28	14	29	0.61
	<i>Pomacanthus semicirculatus</i> AD	24	8	3	2	5	1	5	0.85
	<i>Pomacanthus sexstriatus</i> AD	44	18	11	2	11	1	1	0.91
Pomacentridae	<i>Chromis nitida</i> AD	893	620	130	1	90	3	49	2.32
	<i>Pomacentrus australis</i> AD	405	115	37	31	25	60	137	1.04
	<i>Pomacentrus nagasakiensis</i> AD	255	60	44	31	69	12	39	0.68

family	sci.name	$\Sigma MaxN$	Pompeys		Swains		Cap-Bunks		G:b
			G	b	G	b	G	b	
	<i>Pristotis jerdoni AD</i>	2296	0	1	9	430	1306	550	1.34
Scaridae	<i>Scarus flavipectoralis AD</i>	50	10	13	3	23	1	0	0.39
	<i>Scarus schlegeli AD</i>	23	0	4	3	6	4	6	0.44
Siganidae	<i>Siganus argenteus AD</i>	162	19	45	27	1	30	40	0.88
	<i>Siganus punctatus AD</i>	30	7	11	4	8	0	0	0.58
Tetraodontidae	<i>Lagocephalus sceleratus AD</i>	168	1	0	1	0	79	87	0.93

Negative binomial models to detect effects and interactions amongst zone, reef group and habitat

Plots of the species counts showed that they were highly over-dispersed (mean ~63.7, variance ~3228.5), even when the data was truncated to remove species with more than 100 individuals (such as schooling *Pterocaesio* spp and *Chromis nitida*).

A negative-binomial model was used to handle the over-dispersion of raw counts, as in the previous analyses conducted by Dr W. Venables on BRUVS data for the 'southern shoals' (see Stowar *et al.* 2008).

A null model provided starting points for the mean $MaxN$ ($\exp(4.15520) = 63.76$ fish) and the overdispersion parameter, θ ($=2.106$). A succession of models was then fitted incorporating main effects (zones, reef groups, habitat categories) and their interactions. These showed differences in overall fish abundance among habitats, but with higher abundance around 'green' reefs only in coral-dominated habitats.

Likelihood-ratio tests using an evolution of twelve models showed that the habitat-based model (abundance ~depth + habitat category + habitat category* zone) was the most appropriate (best-fitting) model to quantify regional differences amongst reef groups. This enabled us to account for the differences observed amongst habitats and zones -- especially for 'target' species (Figure 17).

The model estimates in Table 7, Table 10 and Figure 19 show that $MaxN$ was about three to four more 'target' fish (or about 1.5 times higher) on coral-dominated habitats around green reefs, compared to the same habitats around blue reefs.

Table 7: Coefficients for the negative-binomial model of $\sum MaxN$ for all 'target' species, irrespective of their rarity in the dataset. The effect-size estimates are on an exponential scale. The only evidence of a zoning effect was about 1.5 more fish on BRUVS sets on coral-dominated habitats around 'green' reefs than around coral-dominated 'blue' reefs.

source	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-0.82	0.45	-1.84	0.07
depth	0.03	0.01	3.59	<0.0001
Coral dominated	1.81	0.39	4.69	<0.0001
Gorgonians/whips	1.75	0.39	4.53	<0.0001
Low relief rubble	1.40	0.38	3.67	<0.0001
Open sand	0.74	0.39	1.87	0.06
Algal meadows:Green	0.14	0.44	0.33	0.74
Coral dominated:Green	0.42	0.19	2.24	0.02
Gorgonians/whips:Green	-0.03	0.17	-0.19	0.85
Low relief rubble:Green	-0.31	0.16	-1.93	0.05
Open sand:Green	0.12	0.20	0.62	0.53

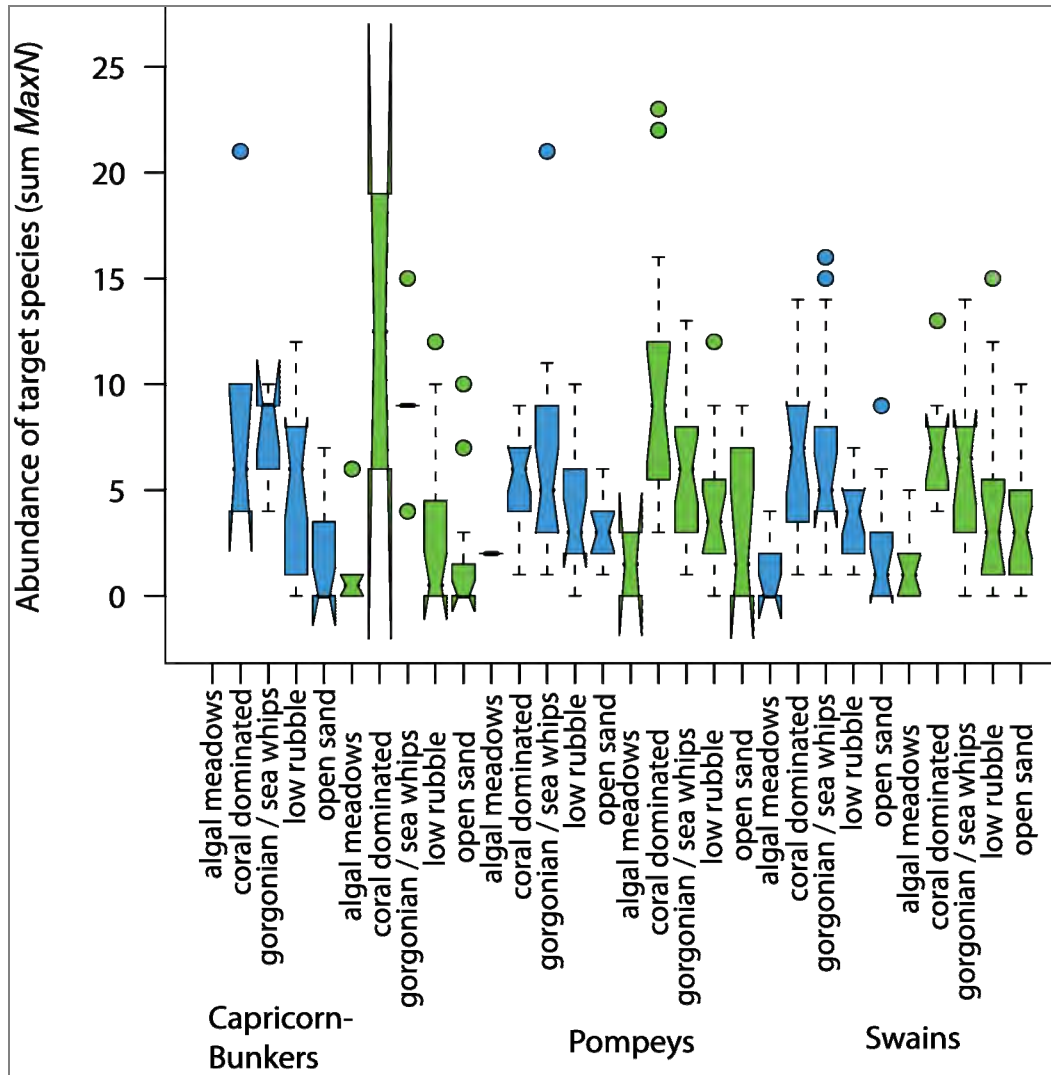


Figure 17: Boxplot of counts (ΣMaxN) of target species in reef groups 'open' (blue) and 'closed' (green) to fishing, showing the median and 95% Confidence Intervals. The notches represent $1.5 \times (\text{interquartile range of } \text{MaxN}/\text{SQRT}(n))$. If the notches do not overlap this is 'strong evidence' that the two medians differ, independent of any assumptions about normality of data distributions or equivalence of variances.

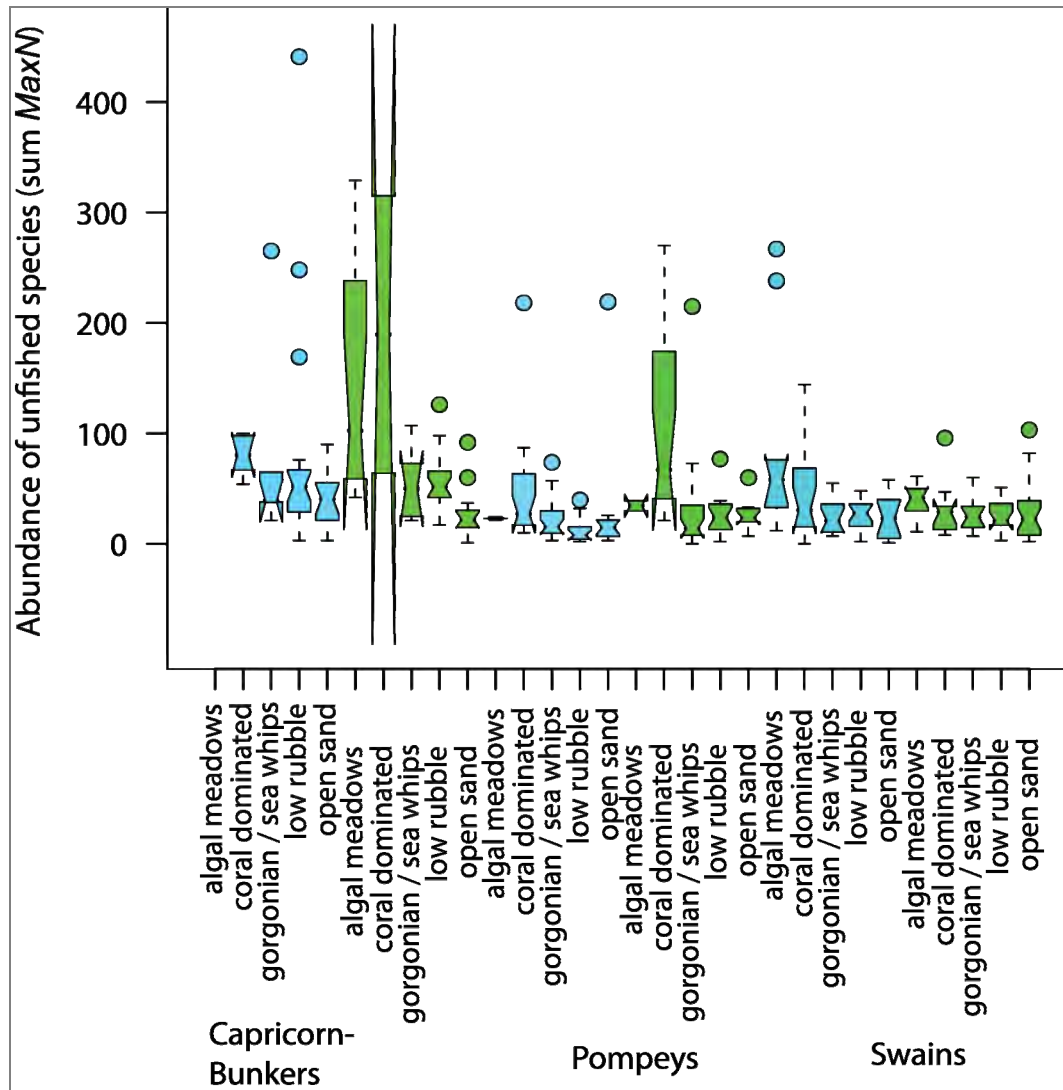


Figure 18: Boxplot of counts ($\Sigma MaxN$) of target species in reef groups 'open' (blue) and 'closed' (green) to fishing, showing the median and 95% Confidence Intervals. All conventions follow Figure 17.

There were no significant differences detected for the 'bycatch' species (Table 7) , but there were about two more individuals in coral-dominated habitats around green reefs relative to blue reefs (Table 8, Table 10, Figure 19). Unfished species were nearly twice as abundant in coral dominated habitats of green reefs (Table 10, Figure 19).

Table 8: Coefficients for the best fitting negative-binomial model of all 'bycatch' species, irrespective of their rarity in the dataset. The estimates are on an exponential scale. There were no apparent effects of zoning, but depth and habitat categories were important factors.

source	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	1.27	0.42	3.03	0.0024
depth	0.03	0.01	3.54	0.0003
Coral dominated	0.74	0.34	2.16	0.03
Gorgonians/whips	0.75	0.34	2.20	0.03
Low relief rubble	0.18	0.33	0.55	0.58
Open sand	-0.01	0.34	-0.03	0.98
Algal meadows:Green	-0.04	0.37	-0.12	0.91
Coral dominated:Green	0.10	0.24	0.42	0.67
Gorgonians/whips:Green	-0.22	0.21	-1.05	0.30
Low relief rubble:Green	0.13	0.19	0.71	0.48
Open sand:Green	0.18	0.21	0.87	0.39

Table 9: Coefficients for the best fitting negative-binomial model of pooled $\sum MaxN$ of all 'unfished' species, irrespective of their rarity in the dataset. The estimates are on an exponential scale. The only marginally significant effect of zoning was about seven more individual fish on BRUVS sets on coral-dominated habitats around 'green' reefs.

source	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	5.77	0.37	15.67	<0.0001
depth	-0.04	0.01	-5.20	<0.0001
Coral dominated	-0.66	0.30	-2.19	0.03
Gorgonians/whips	-0.99	0.30	-3.30	0.009
Low relief rubble	-0.86	0.29	-2.95	0.003
Open sand	-1.07	0.30	-3.55	0.0003
Algal meadows:Green	-0.21	0.32	-0.66	0.51
Coral dominated:Green	0.61	0.21	2.84	0.004
Gorgonians/whips:Green	0.05	0.19	0.29	0.77
Low relief rubble:Green	0.10	0.17	0.57	0.57
Open sand:Green	0.04	0.19	0.21	0.83

Several prized species showed higher *MaxN* in coral dominated habitats around green reefs, as did the grey reef shark. This species is taken mainly as bycatch, and was also more abundant in the 'green' open sand and rubble habitats, compared to the same habitats around blue reefs (Table 11). In contrast, the Venus tuskfish was less abundant on green reefs. Unfished species were nearly twice as abundant in coral dominated habitats of green reefs (Figure 19).

Table 10: Means of *MaxN* for species groups (per BRUVS set) in the 'blue' and 'green' zones. Means, differences and ratios between means in coral dominated habitats are also shown. An effect of zoning was detected in this habitat category, where there were 1.5 times as many 'target' species, and 1.9 times as many 'unfished' species recorded on BRUVS in the green zones.

Species group	All habitats	Coral.dominated habitats	Difference (G-B); coral.dominated habitats	Ratio G:B; coral.dominated habitats
GREEN				
Target	4.56	9.50	3.24	1.52
Bycatch	14.93	20.78	1.91	1.10
Unfished	48.11	98.76	47.16	1.91
All species	66.92	124.90	48.82	1.64
BLUE				
Target	4.59	6.25		
Bycatch	14.61	18.86		
Unfished	41.42	51.60		
All species	60.84	76.10		

Table 11: Differences in mean *MaxN* of individual species per BRUVS set in the five habitat categories where there was evidence of an effect of closure to fishing. The p-value ($P < |z|$) is shown in brackets. For example, for every ten BRUVS sets on green reefs, there were about an additional six red emperor seen in coral dominated habitats, and about eight less Venus tuskfish seen in rubble habitats, relative to the same habitats around blue reefs.

common name	species	Open sand	Algal meadows	Low relief rubble	Gorgonians/ Sea whips	Coral dominated
Prized targets						
Coral trout	<i>Plectropomus leopardus</i>					1.08 (0.12)
Red-throat emperor	<i>Lethrinus miniatus</i>					0.71 (0.21)
Red emperor	<i>Lutjanus sebae</i>					0.62 (0.01)
Venus tusk fish	<i>Choerodon venustus</i>			-0.84 (0.01)		
Bycatch						
Grey reef shark	<i>Carcharhinus amblyrhynchos</i>	0.35 (0.01)		0.35 (0.01)		0.55 (0.02)
Unnamed emperor	<i>Lethrinus semicinctus</i>	1.48 (<0.001)				
Unfished						
Unnamed threadfin bream	<i>Pentapodus nagasakiensis</i>			7.98 (0.04)	3.24 (0.02)	

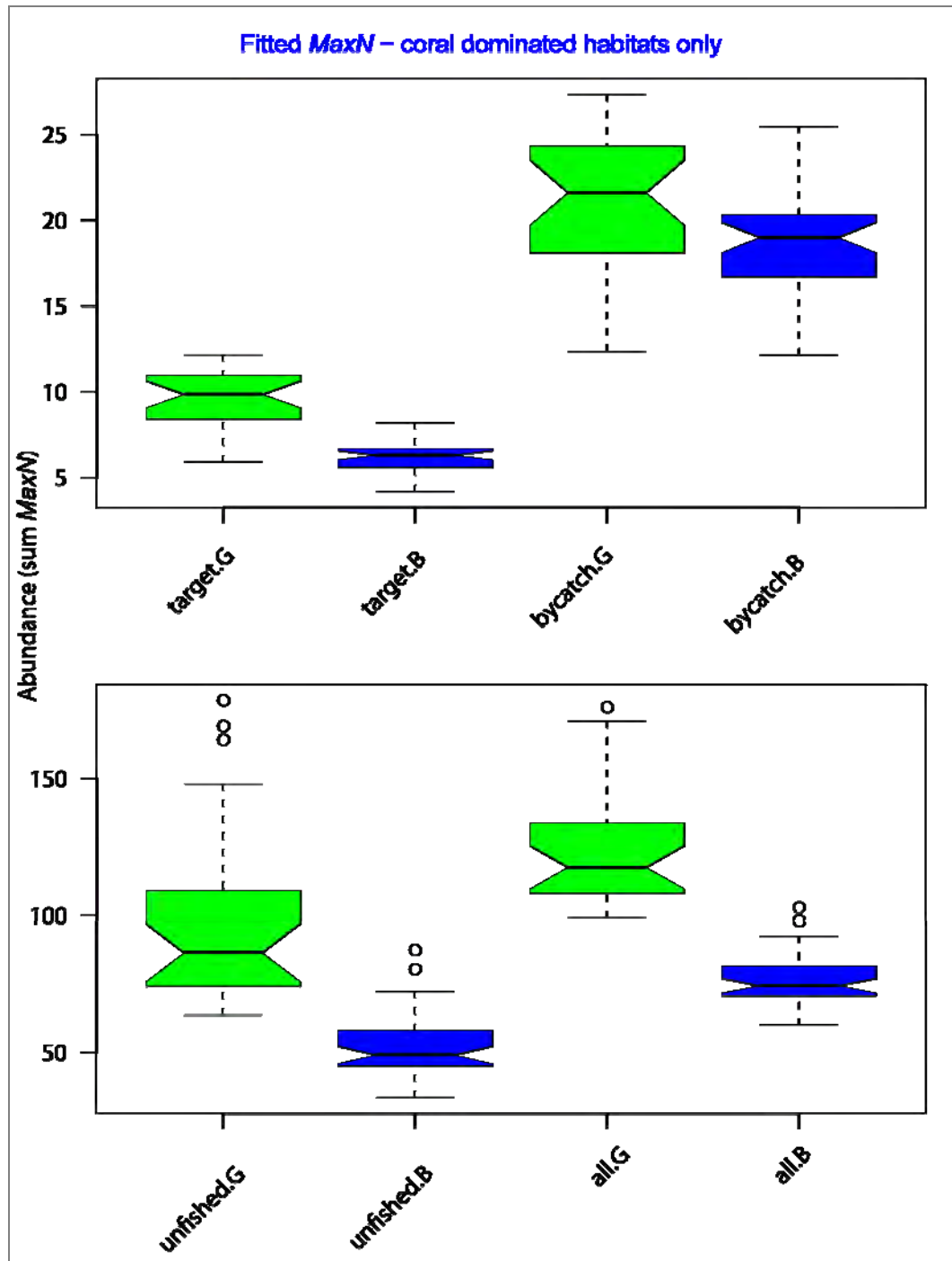


Figure 19: Boxplot of model values (fitted $\Sigma MaxN$) for species groups in coral dominated habitats of zones 'open' (blue) and 'closed' (green) to fishing, showing the median and 95% Confidence Intervals. The notches represent 1.5x (interquartile range of $MaxN/SQRT(n)$). If the notches do not overlap this is 'strong evidence' that the two medians differ, independent of any assumptions about normality of data distributions or equivalence of variances.

Discussion

The deep water reef bases surveyed in this study had rich vertebrate faunas, demonstrating the importance of these habitats to biodiversity conservation and fisheries sustainability in the region.

The reef bases selected for the study followed the pair-wise comparisons published by Russ *et al.* (2008) for shallow-water coral trout *Plectropomus leopardus*. Reef pairs were matched by reef size, distance from shore, wave exposure and general underwater topography. In most cases there was no prior information on fishes or other reef communities. The proportional difference in density of coral trout between no-take and open reefs after rezoning showed increases in the Pompey (+57%), Swain (+31%) and Capricorn-Bunker (+64%) groups.

Coral trout are site-attached at the scale of individual reefs, so valid green-blue comparisons can be made confidently between reefs separated by very small distances [hundreds of metres] across deep channels and sand plains. In contrast, some of the 'shoal' serranids, lethrinids and lutjanids counted by us around reef bases are known from the movements of tagged individuals to be mobile at the level of tens to hundreds of kilometers (Maplestone *et al.* 2006).

A significant number of the reef pairs were found to be poorly suited to the pair-wise comparison of zoning effects around reef bases, because there were strong differences in habitat types between reefs within pairs and amongst the Pompey, Swain and Capricorn-Bunkers reef groups. In particular, the Capricorn-Bunker reef group had relatively few BRUVS sets in coral-dominated habitats due to the steep nature of reef drop-offs into relatively shallow water.

The Capricorn-Bunker group lies on a sand shelf arising from the long-shore deposition of sand from the Fraser Island coast, and had abundant low relief habitats (such as algal meadows) in clear waters of low tidal energy (Pitcher *et al.* 2007). The Pompey group had strong tidal currents and rich filter-feeding communities around reef bases, whereas the Swains reefs had steep slopes to carbonate sand plains, with deep-water coral-dominated communities common on the reef base.

Our study was the first examination of these uncharted or incompletely charted reef bases, with adverse weather conditions and no resources for time-consuming searches for 'favourable habitat'. Instead, BRUVS were dropped along depth contours in the sheltered lee of reefs at safe distances from the reef edge. In terms of proximity of reefs within pairs, consistency of distribution of rugose habitats, and proximity to fishing ports, the outer Pompeys beyond the Tern Islet/Penrith Island pair offered the best reef group to assess the effects of zoning.

Whilst the emergent reef flats and reef slopes of the sixteen pairs of reefs were easily recognizable as separate entities in the study by Russ *et al.* (2008), we found that the reef bases were sometimes contiguous patches of rugose habitat that extended between reefs within blue-green pairs. In some pairs, such as Wade Reef and 22084S in the Swain group, 'blue' and 'green' reefs were separated only by narrow channels tens of metres wide. It was almost certain that the 'shoal' species move freely between such reefs along suitable corridors of habitat.

Despite these limitations, the coarse ratios of *MaxN* consistently showed more 'target' and 'bycatch' species on BRUVS set around the bases of green reefs, particularly in the Pompey group. These coarse signals were diluted somewhat once habitat types and reef groups were

taken into account in negative-binomial models. The *MaxN* for aggregated groups of species taken as bycatch were similar in both 'blue' and 'green' zones, but the 'target' group *MaxN* was higher around green reefs in coral dominated habitats by about three to four individuals. In this habitat type, 'target' species were about 1.5 times, and unfished species about 1.9 times, as abundant in the 'green' zones as the same groups in the 'blue' zones.

The responses to zoning of the 21 'target' species varied in magnitude, and the Venus tuskfish (*Choerodon venustus*) had slightly lower *MaxN* in rubble habitat around 'green' reefs. There was strong evidence that the *MaxN* of the deep water coral trout, red throat emperor and red emperor, prized most by recreational and commercial line fishers, were slightly higher in the coral-dominated habitats of reefs closed to fishing relative to those open to fishing. Grey reef sharks, which are taken as bycatch or intentionally, had slightly higher *MaxN* in a range of open and complex habitats around green reef bases. For every ten BRUVS sets, there were about eleven coral trout, six red emperor and five grey reef sharks more in green zones than in similar coral dominated habitats of blue zones.

The consistency of the response of most 'target' species, both individually and when aggregated in analyses, strongly suggests a positive effect of zoning. This observation was predictable given that mortality due to fishing is likely to be greater in the areas open to fishing than in comparable areas closed to fishing (e.g. Russ *et al.* 2008).

The lack of a striking effect of zoning in the present study should not be overstated. It may be the case that the level of fishing effort around the reef bases in the southern GBRMP was as low as to fall within the range of natural mortality caused by storms and other disturbances. Shallow-water coral trout are the major target of commercial dorymen in the area, for the international trade in live reef fish. Commercial and charter operations that do pursue deeper shoal species in the region operate elsewhere, around banks and discrete shoals in the Capricorn Channel and on the drop-off from the outer reef to the continental slope (see Mapleston *et al.* 2006).

Unlike coral trout, the sharks, lutjanids and lethrinids of deeper water are known to have relatively advanced longevity and slow growth rates (e.g. Newman *et al.* 1996, 2000; Williams *et al.* 2003), and it may be too early to detect an accumulation of new stock since the relatively recent rezoning in 2004. Red emperor can reach at least forty years of age, and even small lutjanid species can have longevity over twenty years (Newman *et al.* 1996; Newman and Dunk 2002). The large size, high age at first maturity (12+ years) and low fecundity (one pup every second year in younger females) of grey reef sharks imply a long recovery time for populations (Robbins *et al.* 2006) released from the pressure of fishing.

The results presented here contribute to a growing body of scientific evidence that the abundance and/or biomass of selected target species is often enhanced within areas closed to fishing relative to comparable areas open to fishing (e.g. Halpern and Warner 2002; Evans *et al.* 2006; Mapstone *et al.* 2005; Russ *et al.* 2008; Watson *et al.* 2007; Williamson *et al.* 2004).

Major factors that contribute to uncertainty in assessing and understanding the effects of zoning on these fish communities around reef bases include:

- Paucity of knowledge of reef-specific fishing effort, catch composition and mortality of by-catch by the recreational and commercial fishing sectors;
- Complex movements and variable life histories of the fish species that often span zoning boundaries;
- The close proximity of study reefs to zoning boundaries, with connectivity among reefs along corridors of suitable habitat confounding pair-wise comparisons; and

- The difficulty of linking habitat variables to deep fish communities on spatial scales appropriate to science and management.

Dealing with this uncertainty demands robust statistical designs for studying effects of zoning on fish communities. We have demonstrated once more the potential of BRUVS for rapidly, routinely and non-intrusively monitoring fish populations in deepwater habitats of the GBRMP. Continuation of this monitoring on known habitat features will provide future indications of longer term effects of the RAP 2004 rezoning.

The deep regions of the GBR outer shelf, and the inter-reef plains, remain largely unexplored in the GBRMP. Deep-water reefs, palaeo-lagoons and pinnacles are now known to extend outside the outer reef down to the shelf edge in depths over 150m (Harris *et al.* 2005). A diverse range of phototrophic (algae, seagrass, octocorals) and heterotrophic communities (filter-feeders) have also been documented in the inter-reefal plains, channels and lagoon below the limits of SCUBA (Pitcher *et al.* 2007). These diverse habitats have various degrees of productivity and topography recognised internationally as 'Essential Fish Habitat' (Koenig *et al.* 2000) for tropical and sub-tropical snapper-grouper assemblages (Coleman *et al.* 2000). They must play a similar, but poorly documented, role in the GBRMP.

References

AIMS (2006) BRUVS database v2.1.04[®]. Australian Institute of Marine Science, Townsville.

Ayling, A. M. and Choat, J. H. (2008) Abundance patterns of reef sharks and predatory fishes on differently zoned reefs in the offshore Townsville region. Final Report to the Great Barrier Reef Marine Park Authority. Research Publication No. 91, Great Barrier Reef Marine Park Authority, Townsville (32pp.).

Begg, G. A., Mapstone, B. D., Williams, A. J., Adams, S., Davies, C. R. and Lou, D. C. (2005) Multivariate life-history indices of exploited coral reef fish populations used to measure the performance of no-take zones in a marine protected area. *Canadian Journal of Fisheries and Aquatic Sciences* 62: 679-692.

Cappo, M., Harvey, E., Malcolm, H. and Speare, P. (2003) Potential of video techniques to monitor diversity, abundance and size of fish in studies of marine protected areas. In: Beumer, J. P., Grant, A. and Smith, D. C. (eds.) *Aquatic Protected Areas: What works best and how do we know?* Australian Society for Fish Biology (ASFB) World Congress on Aquatic Protected Areas, Cairns, Australia.

Cappo, M., Speare, P. and De'ath, G. (2004) Comparison of baited remote underwater video stations (BRUVS) and prawn (shrimp) trawls for assessments of fish biodiversity in inter-reefal areas of the Great Barrier Reef Marine Park. *Journal of Experimental Marine Biology and Ecology* 302: 123-152.

Cappo, M., De'ath, G. and Speare, P. (2007) Shelf-scale patterns in communities of aquatic vertebrates in the inter-reefal waters of the Great Barrier Reef Marine Park determined by Baited Remote Underwater Video Stations. *Marine Ecology Progress Series* 350: 209-221.

Coleman, F. C., Koenig, C. C., Huntsman, G. R., Musick, J. A., Eklund, A. M., McGovern, J. C., Chapman, R. W., Sedberry, G. R. and Grimes, C. B. (2000) Long-lived reef fishes: The grouper-snapper complex. *Fisheries* 25:14-21.

Coleman, F. C., Figueira, W. F., Ueland, J. S. and Crowder, L. B. (2005) Global impact of recreational fisheries - Response. *Science* 307:1562-1563.

Evans, R. D., Williamson, D. H., Sweatman, H., Russ, G. R., Emslie, M., Cheal, A. and Miller, I. (2006) Surveys of the effects of rezoning of the GBR Marine Park in 2004 on some fish species – Preliminary findings. Project Report to the Marine and Tropical Sciences Research Facility, Townsville (17pp.).

Fernandes, L., Day, J., Lewis, A., Slegers, S., Kerrigan, B., Breen, D., Cameron, D., Jago, B., Hall, J., Lowe, D., Innes, J., Tanzer, J., Chadwick, V., Thompson, L., Gorman, K., Simmons, M., Barnett, B., Sampson, K., De'ath, G., Mapstone, B., Marsh, H., Possingham, H., Ball, I., Ward, T., Dobbs, K., Aumend, J., Slater, D. and Stapleton, K. (2005) Establishing representative no-take areas in the Great Barrier Reef: Large-scale implementation of theory on marine protected areas. *Conservation Biology* 19: 1733-1744.

Graham, N. A. J., Evans, R. D. and Russ, G. R. (2003) The effects of marine reserve protection on the trophic relationships of reef fishes on the Great Barrier Reef. *Environmental Conservation* 30(2): 200-208.

Halpern, B. S. and Warner, R. R. (2002) Marine reserves have rapid and lasting effects. *Ecology Letters* 5: 361-366.

Harris, P. T., Heap, A., Passlow, V., Hughes, M., Daniell, J., Hemer, M. and Anderson, O. (2005) Tidally incised valleys on tropical carbonate shelves: An example from the northern Great Barrier Reef, Australia. *Marine Geology* 220: 181-204.

Johansson, C., Stowar, M. and Cappo, M. (2008) [*The use of stereo BRUVS for measuring fish size*](#). Report to the Marine and Tropical Sciences Research Facility. Reef and Rainforest Research Centre Limited and Australian Institute of Marine Science, Townsville (20pp.).

Koenig, C. C., Coleman, F. C., Grimes, C. B., Fitzhugh, G. R., Scanlon, K. M., Gledhill, C. T. and Grace, M. (2000) Protection of fish spawning habitat for the conservation of warm-temperate reef-fish fisheries of shelf-edge reefs of Florida. *Rosenstiel School of Marine and Atmospheric Science*, p. 593-616.

Mapstone, B. D., Davies, C. R., Little, L. R., Punt, A. E., Smith, A. D. M., Pantus, F., Lou, D. C., Williams, A. J., Jones, A., Ayling, A. M., Russ, G. R. and McDonald, A. D. (2005) [*The effects of line fishing on the Great Barrier Reef and evaluations of alternative potential management strategies*](#). CRC Reef Technical Report No. 52. CRC Reef Research Centre, Townsville. 202pp.

Mapleston, A., Begg, G. A., Ballagh, A., Goldman, B. and Williams, A. J. (2006) *Monitoring the effects of re-zoning on nonreef habitats of the Great Barrier Reef: Identifying locations and harvested species of interest*. Report to CRC Reef Research Centre Limited, Townsville (49pp.).

Pitcher, C. R., Doherty, P., Arnold, P., Hooper, J., Gribble, N., Bartlett, C., Browne, M., Campbell, N., Cannard, T., Cappo, M., Carini, G., Chalmers, S., Cheers, S., Chetwynd, D., Colefax, A., Coles, R., Cook, S., Davie, P., De'ath, G., Devereaux, D., Done, B., Donovan, T., Ehrke, B., Ellis, N., Ericson, G., Fellegara, I., Forcey, K., Furey, M., Gledhill, D., Good, N., Gordon, S., Haywood, M., Hendriks, P., Jacobsen, I., Johnson, J., Jones, M., Kinninmonth, S., Kistle, S., Last, P., Leite, A., Marks, S., McLeod, I., Oczkowicz, S., Robinson, M., Rose, C., Seabright, D., Sheils, J., Sherlock, M., Skelton, P., Smith, D., Speare, P., Stowar, M., Strickland, C., Van Der Geest, C., Venables, W., Walsh, C., Wassenberg, T., Welna, A. and Yearsley, G. (2007) [*Seabed Biodiversity on the Continental Shelf of the Great Barrier Reef World Heritage Area*](#). AIMS/CSIRO/QM/QDPI&F Report to the CRC Reef Research Centre Limited, Final Report (315pp.).

Newman, S. J., Williams, D. M. and Russ, G. R. (1996) Age validation, growth and mortality rates of the tropical snappers (Pisces: Lutjanidae) *Lutjanus adetii* (Castelnau, 1873) and *L. quinquelineatus* (Bloch, 1790) from the central Great Barrier Reef, Australia. *Marine and Freshwater Research* 47: 575-584.

Newman, S. J., Cappo, M. and Williams, D. M. (2000) Age, growth, mortality rates and corresponding yield estimates using otoliths of the tropical red snappers, *Lutjanus erythropterus*, *L. malabaricus* and *L. sebae*, from the central Great Barrier Reef. *Fisheries Research* 48: 1-14.

Newman, S. J. and Dunk, I. J. (2002) Growth, age validation, mortality, and other population characteristics of the red emperor snapper, *Lutjanus sebae* (Cuvier, 1828), off the Kimberley coast of north-western Australia. *Estuarine Coastal and Shelf Science* 55: 67-80.

R Development Core Team (2006) *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria (ISBN 3-900051-07-0) (URL <http://www.R-project.org>).

Robbins, W. D., Hisano, M., Connolly, S. R. and Choat, J. H. (2006) Ongoing collapse of coral-reef shark populations. *Current Biology* 16: 2314-2319.

Russ, G. R., Cheal, A. J., Dolman, A. M., Emslie, M. J., Evans, R. D., Miller, I., Sweatman, H. and Williamson, D. H. (2008) Rapid increase in fish numbers follows creation of the world's largest marine reserve network. *Current Biology* 18(12): R514-R515.

Speare, P. and Stowar, M. (2007) [*Preliminary findings from the first baseline survey of the Magnetic Shoals*](#). Report to the Marine and Tropical Sciences Research Facility. Reef and Rainforest Research Centre Limited and Australian Institute of Marine Science, Townsville (22pp.).

Stowar, M., De'ath, G., Doherty, P., Johansson, C., Speare, P. and Venables, B. (2008) [*Influence of zoning on midself shoals from the southern Great Barrier Reef*](#). Report to the Marine and Tropical Sciences Research Facility. Reef and Rainforest Research Centre Limited and Australian Institute of Marine Science, Townsville (90pp.).

Watson, D. L., Harvey, E. S., Kendrick, G. A., Nardi, K. and Anderson, M. J. (2007) Protection from fishing alters the species composition of fish assemblages in a temperate-tropical transition zone. *Marine Biology* 152: 1197-1206.

Williams, A. J., Davies, C. R., Mapstone, B. D. and Russ, G. R. (2003) Scales of spatial variation in demography of a large coral reef fish: an exception to the typical model? *Fishery Bulletin* 101: 673-683.

Williamson, D. H., Russ, G. R. and Ayling, A. M. (2004) The effectiveness of marine reserves in protecting fish stocks on fringing reefs of the Great Barrier Reef Marine Park. *Environmental Conservation* 31(2): 149-159.

Appendices

Appendix 1: Details of deployments of BRUVS in the sixteen pairs of reef bases open and closed to fishing in the Pompey, Swain and Capricorn-Bunker groups of reefs in the southern GBRMP. The reef pair number follows Russ *et al.* (2008). The number of useful replicates (*N*) is shown with minimum, mean and maximum depth (*d*) in metres. The beginning (Start) and end (End) positions of the line along which BRUVS were set are shown in decimal degrees. The number of BRUVS sets classified by habitat categories within reefs are shown as: *sand* (OPEN SANDY SEABED), *rubbl* (LOW RELIEF RUBBLE FIELD), *alg* (ALGAL MEADOW), *gorg* (GORGONIAN and SEAWHIP GARDEN), and *crl.dom* (CORAL DOMINATED REEF).

rf.pair	zone	Reef name	<i>N</i>	Start lat. °S	Start long. °E	End lat. °S	End long. °E	d.min	d.mean	d.max	<i>sand</i>	<i>rubbl</i>	<i>alg</i>	<i>gorg</i>	<i>crl.dom</i>
Pompey Reef group															
13	b	21060S	10	-21.015129	150.857393	-21.006482	150.58834	37.4	42.5	48.3	3	5	-	2	-
13	G	POMPEY REEF#1	12	-21.324763	152.574112	-21.952606	152.295919	30.7	35.8	42.3	6	2	-	4	-
14	b	21591S	12	-23.76335	152.250533	-23.517975	151.710714	16.8	29.6	40.7	-	3	1	3	5
14	G	POMPEY REEF#2	12	-23.179382	151.922899	-21.029081	150.849284	14	19.4	27	1	1	2	1	7
15	b	21062S	11	-21.046931	150.780984	-21.408666	151.620616	27.6	34.4	41.4	5	-	-	4	2
15	G	20348S	10	-21.022218	150.589496	-21.027315	150.849478	29.6	37.2	43	1	7	-	2	-
16	b	21064S	12	-21.405486	151.641338	-21.30675	152.420026	27.7	32.5	36.4	3	-	-	5	4
16	G	20353S	12	-21.029812	150.383954	-21.011349	150.384207	29.6	35.4	40	2	-	-	10	-
17	b	21187S	12	-21.296326	152.436604	-21.86915	152.500749	30.6	36.6	40.2	-	4	-	5	3
17	G	21139S	12	-21.000261	149.904641	-21.313779	152.56361	30.7	34.4	40	-	4	-	-	8
18	b	PENRITH REEF	12	-21.558952	152.520912	-23.244784	151.93714	19	28.3	34	1	3	-	3	5
18	G	TERN REEF	10	-23.845436	152.370876	-21.477117	151.449808	31.8	39.1	48.4	-	2	-	8	-
Swain Reef group															
19	b	21245S	12	-21.862836	152.528038	-23.855305	152.357599	31	33.9	36	2	-	5	-	5
19	G	21278S	12	-21.992136	152.663919	-20.9721	150.532867	38.2	41.4	45	1	6	4	-	1
20	b	SMALL LAGOON REEF	12	-23.808074	152.272497	-21.101083	152.5338	34	37.1	44	4	5	-	3	-
20	G	JENKINS REEF	12	-21.112431	152.540849	-21.997514	152.658599	32	40	46	6	1	3	2	-
21	b	CHINAMAN REEF(22102)	12	-20.994667	150.501683	-23.798188	152.284144	29	35.5	44	5	2	-	1	4
21	G	WADE REEF	12	-23.491816	151.78063	-20.969675	150.90526	38.2	41.6	45	5	5	-	2	-

rf.pair	zone	Reef name	N	Start lat. °S	Start long. °E	End lat. °S	End long. °E	d.min	d.mean	d.max	sand	rubbl	alg	gorg	crl.dom
22	b	21550S	12	-21.436297	152.566562	-21.464672	152.562081	30	34.6	38	2	-	3	5	2
22	G	22084S	12	-23.902667	152.381417	-21.98198	152.640077	29.3	31.6	34	7	2	-	3	-
23	b	EAST CAY REEF	11	-20.874276	150.943256	-21.007735	150.58735	31	35.5	40	-	6	1	3	1
23	G	21558S	12	-23.262926	151.957518	-20.910749	150.513056	33	38.3	44	3	1	-	2	6
24	b	21302S	11	-21.484523	152.547461	-20.895255	150.935781	29	35.6	42	-	6	-	1	4
24	G	21296S	11	-21.938455	152.324942	-21.420712	152.578266	31	37.4	40	2	-	4	3	2
Capricorn-Bunker Reef group															
25	b	BROOMFIELD REEF	12	-20.919657	150.561617	-23.17428	151.89968	33.2	36.4	38.4	-	7	-	4	1
25	G	NORTH REEF (NORTH)	12	-22.001485	152.449279	-23.915165	152.381076	32	36.2	39.2	-	6	-	4	2
26	b	BOULT REEF	12	-23.523544	151.738847	-21.993688	152.470903	32	36.8	39.2	5	5	-	1	1
26	G	HOSKYN ISLANDS REEF	12	-20.901725	150.03817	-23.497399	151.765424	32.4	36.5	40.7	8	4	-	-	-
27	b	LADY MUSGRAVE REEF	12	-21.96393	152.581145	-21.963895	152.591584	23	25.3	28	3	5	-	-	4
27	G	FAIRFAX ISLANDS REEF	12	-21.456339	151.453586	-21.009951	149.88361	30	34.7	39	1	9	1	1	-
28	b	MAST HEAD REEF	12	-21.992189	152.649044	-21.007735	150.58735	16.2	19.1	23.7	8	4	-	-	-
28	G	ERSKINE REEF	12	-20.952217	150.904312	-21.01071	150.372942	21	25.3	28.2	2	1	9	-	-

Appendix 2: Summaries of habitat and fish categorisation of BRUVS data in the sixteen pairs of reef bases open (b) and closed (G) to fishing in the Pompey, Swain and Capricorn-Bunker groups of reefs in the southern GBRMP. The reef pair number follows Russ *et al.* (2008). The number of BRUVS sets classified by habitat categories within reefs are shown as: *sand* (OPEN SANDY SEABED), *rubbl* (LOW RELIEF RUBBLE FIELD), *alg* (ALGAL MEADOW), *gorg* (GORGONIAN and SEAWHIP GARDEN), and *crl.dom* (CORAL DOMINATED REEF). The total number ($\Sigma MaxN$) of fishes, sharks and rays classified as *tar* (PRIZED TARGETS), *byc* (BYCATCH) and *not* (UNFISHED) are shown. Pooled sightings in all categories are shown as *allf* (ALL SPECIES).

rf.pair	zone	reef	<i>sand</i>	<i>rubbl</i>	<i>alg</i>	<i>gorg</i>	<i>crl.dom</i>	<i>tar</i>	<i>byc</i>	<i>not</i>	<i>allf</i>
Pompey Reef group											
13	b	21060S	3	5	-	2	-	39	67	163	269
13	G	POMPEY REEF (NO 1)	6	2	-	4	-	1	17	886	904
14	b	21591S	-	3	1	3	5	22	73	140	235
14	G	POMPEY REEF (NO 2)	1	1	2	1	7	63	163	275	501
15	b	21062S	5	-	-	4	2	38	97	152	287
15	G	20348S	1	7	-	2	-	75	122	692	889
16	b	21064S	3	-	-	5	4	41	193	590	824
16	G	20353S	2	-	-	10	-	32	242	283	557
17	b	21187S	-	4	-	5	3	70	138	199	407
17	G	21139S	-	4	-	-	8	92	251	371	714
18	b	PENRITH REEF	1	3	-	3	5	55	219	622	896
18	G	TERN REEF(20309)	-	2	-	8	-	118	262	1366	1746
Swain Reef group											
19	b	21245S	2	-	5	-	5	88	307	264	659
19	G	21278S	1	6	4	-	1	33	195	297	525
20	b	SMALL LAGOON REEF	4	5	-	3	-	33	176	420	629
20	G	JENKINS REEF	6	1	3	2	-	55	172	434	661
21	b	CHINAMAN REEF(22102)	5	2	-	1	4	71	128	390	589
21	G	WADE REEF	5	5	-	2	-	42	137	296	475
22	b	21550S	2	-	3	5	2	57	201	392	650

rf.pair	zone	reef	sand	rubbl	alg	gorg	crl.dom	tar	byc	not	allf
22	G	22084S	7	2	-	3	-	49	144	287	480
23	b	EAST CAY REEF	-	6	1	3	1	52	245	916	1213
23	G	21558S	3	1	-	2	6	73	350	340	763
24	b	21302S	-	6	-	1	4	31	199	276	506
24	G	21296S	2	-	4	3	2	36	168	437	641
Capricorn-Bunker Reef group											
25	b	BROOMFIELD REEF	-	7	-	4	1	53	216	317	586
25	G	NORTH REEF (NORTH)	-	6	-	4	2	96	123	780	999
26	b	BOULT REEF	5	5	-	1	1	86	93	833	1012
26	G	HOSKYN ISLANDS REEF	8	4	-	-	-	21	162	568	751
27	b	LADY MUSGRAVE REEF	3	5	-	-	4	84	308	390	782
27	G	FAIRFAX ISLANDS REEF	1	9	1	1	-	26	98	763	887
28	b	MAST HEAD REEF	8	4	-	-	-	61	123	1033	1217
28	G	ERSKINE REEF	2	1	9	-	-	10	121	1463	1594

Further Information

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